DREDGING OF HARBOURS AND RIVERS

E. C. SHANKLAND, F.R.S.E.

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A Work of Descriptive and Technical Reference
Combining Hydrography, Dredging, Hydraulics and Seamanship

BY

E. C. SHANKLAND, F.R.S.E.

River Superintendent, Port of London
Honours Steam and Electrical Appliances in Ships
Late Admiralty Hydrographic Survey

With Illustrations and Plans

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FOREWORD

BY

Sir JOHN H. BILES, K.C.I.E., LL.D., D.Sc., M.Inst.N.A., M.Inst.C.E., Etc.

The Author has done me the honour to ask me to read his book and write a Foreword to it which I do with the greatest pleasure. Captain Shankland has produced a book which combines the actual operation of dredgers with the economics of typical performance. He also has described the hydrographic work leading up to and following on dredging.

This book is one of a rare number on the subject of dredging. The necessary plant for dredging requires experience and skill in its design and construction, and I have some authority for speaking in this way as my firm has been engaged in superintending the design and construction amongst other things of many dredgers for well over a quarter of a century. During this time very little publicity has been given to the subject. A great deal of skill is also required in the operations of dredging; in this book will be found this side of the subject, dealt with much more fully than it has ever been dealt with before, and by one whose practical experience is very great. The Thames is a waterway which helps London to be the centre of the commerce of the world, and the keeping of this waterway up to and in advance of the requirements of the day is a serious and responsible duty in which Captain Shankland has had the honour of assisting for many years. Perhaps the cutting of the Suez and Panama Canals was a more striking performance of dredging than the maintenance

of the Thames, but while it took the removal of 30 million tons to cut the Suez Canal about 1870 and onwards, the Thames has had removed from it 22 million tons in the last eleven years. In many places other than London large tracts of land are reclaimed by the use of dredgers. A dredger, the *Lord Willingdon*, referred to in this book, has been used in cutting a channel from the sea into Cochin harbour and in reclaiming ground, and the whole scheme has gone through with great success.

Very little has been heard of dredgers, and this book serves the double purpose very thoroughly of telling a great deal about dredgers and how they are worked. Those who are interested in the subject will be greatly indebted to Captain Shankland for the painstaking care which he has devoted to the preparation of this work.

4th May, 1931.

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The Controller, H.M. Stationery Office. (*Admiralty Tide Tables.*)
Encyclo. Brit. 13th Edition. (Hydraulics.)
Hammerton. *Harmsworth Atlas.* (Map-making.)
Wharton & Field. *Hydrographic Surveying.*
J. Bertram Kershaw & Water Engineering. (River Gauging.)
Sir John Biles & Co. Dredger *Lord Willingdon*, Burdwan, Vizagapatam.
Le Grand, Sutcliff & Gill. (Borings.)
Tilbury Contracting & Dredging Company.
Dravo Contracting Coy., Pittsburg, Pa.
Lobnitz & Co., Ltd., Renfrew.
Ferguson Bros., Ltd., Port-Glasgow.
Simons & Co., Ltd., Renfrew.
Baker, G. S. (Ship Form, Resistance and Screw Propulsion.)
Dock & Harbour Authority. Cochin Harbour Dredging.
Bruntons, Ltd. Wire Rope Technique.
Sir Robert Hadfield, Ltd. Dredger Parts. "Era" Manganese Products.
Siebe, Gorman & Co. Diving, Rock Breaking, Drilling.
Priestman Bros., Ltd. Grab Dredging.
Kalis & Co. Reclamation and Dredging.
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Inst. of Mech. Engineers. (See Wilcox.)

CONTENTS.

Dredging of Harbours and Rivers.

ERRATA.

Page	82.	3rd par, 2nd and 3rd line, omit "feet"
,,	115.	2nd par, 4th line, for "continuation" read "combination"; for "dock" read "clock."
,,	145.	2nd par, line 3, for "became" read "become"; 4th par, after 5220 insert "hours."
,,	150.	2nd par, 6th line, omit word "hereinafter."
,,	173.	Hopper XL "Coal 15 tons" should read "× tons."
,,	185.	1st par, 2nd line, delete "is"; for "contributing" read "contributes."

CHAPTER III.

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CONTENTS

ILLUSTRATIONS.

HARBOUR AND RIVER DREDGING

CHAPTER I.

INTRODUCTORY — HISTORICAL — FIRST PRINCIPLES — PHYSICAL CONDITIONS—COMPUTING A DATUM FOR TIDE LEVELS—TIDAL DIAGRAMS.

Introductory.—Some literary works exist dealing with the design, mechanism and general functions of dredgers, but on the hydrography and economics of dredging practice there appear to be few, if any, works of reference.

In view of these deficiencies, this book, constructed largely from experience of actual dredging projects, is offered as a contribution to the subject.

The collection of data was commenced before 1914 over a period of several years when the writer's services were joined with the survey and dredging of Plymouth Sound.

Later, the notes were revived, and when at the Port of London associated with a dredging scheme measured by a channel improvement of 56 million cubic yards—the data were amplified.

More recently on representations that the notes would be of value to the young hydrographic engineer a decision to publish was made.

We have also had in mind during the compilation the work of the British dredger shipbuilder, whose varied plant, while requiring no testimonial from us, deserves more publicity than it appears to receive.

Historical.—The dredging of rivers and canals is an ancient art.

Many thousand years ago the Chinese and the races living on the banks of the Tigris and Euphrates employed dredging for cultivation. The operations then were conducted on much the same principles as those employed to-day. A lever was lowered and raised, at the end of which was a bucket or sand receptacle, at the other some attachment for pulling when the bucket was full—by man power or animal power.

Hand Dredging Punt at Work on the Thames, 1930.

The apparatus was used by the ancients not only to keep the channels clear of silt, thus ensuring the flow of water in the channels, but also to raise water to fertilise the land when it was dry.

To-day if one visits the banks of the Thames between Teddington and Kew you may see an apparatus similar to that used by the Chinese many thousand years ago. On the Thames it is known as spoon and bag dredger and is operated by two men, the one controlling the upper end and another the lower

(or spoon and bag end) by lanyard. The dredging pole is fixed to the side of a barge with an axis which permits of it being worked from the deck and the contents of spoon and bag turned into the hold.

Many thousand tons have thus been removed from the Thames for the purpose of maintaining the channel, providing sand and gravel for the reparation of the river banks and for other purposes.

Holland and Italy both claim to have been the original country to use the spoon and bag dredger, but it is probable that the Phoenicians—or the Romans—may have introduced the method into Britain, having seen it in use in the valleys of the Eastern countries which they visited and conquered before coming Westwards.

The use of iron and steel in shipbuilding, coal and the development of the steam engine enabled a great advance to be made in dredging about 1860. It was this advance which made the dredging of harbours possible on a large scale and also the dredging of such canals as the Suez and of Panama.

To accomplish the first cut of the Suez Canal no less than 30,000,000 tons were removed by dredging. To the present time about 100,000,000 tons have been dredged from that canal.

Dredging machines vary in type. There are bucket dredgers, suction cutters, suction or sand pumping dredgers, grab and dipper arm dredgers.

After the excavation of the material from the bottom of the sea or river, the question of removing the material—or spoil as it is sometimes called—requires special consideration.

In the Suez and other canals the material is usually raised into a high level shute or pipe-line which carries the material on to the land where special arrangements are made for draining the water away at the deposit site.

By this means the excavation can be carried many miles over land at small expenditure of effort or money. In large seaports this is not possible as a rule, the banks being covered by industrial undertakings or used for dwellings. In such

places the spoil is loaded into specially constructed barges, named hoppers, which take it to sea.

Dredgers are also designed to carry the spoil which is raised by their own power in a special tank or hold. They are self-propelled hopper dredgers. The releasing of the load of spoil is simple. The hopper vessels have doors fitted in the bottom of the ship. Before loading these doors are drawn close up by a winch and held in the closed position for as long as required.

When the hopper drops the load at sea the doors are opened and load released. At the side of the hopper are water-tight tanks which keep the vessel afloat quite independently of the opening and closing of the bottom doors. By this method many tons are removed and taken to sea from our seaports in a year.

To enable the effects of dredging to be known, hydrographic surveyors take soundings before and after the dredging operations.

Plans are made showing the depths, and many of those plans form the corrections for Admiralty charts. The mariner by this arrangement is furnished with the latest changes in the depths of the harbour or river.

In the Port of London when it was decided to build docks for large ocean vessels, a channel 50 miles long required to be dredged. This channel was commenced in 1909 and has been completed for a distance of 43 miles. The remaining 7 miles should be completed in a few years. Over 56,000,000 cubic yards will then have been removed.

Some remarkable finds are made in dredging.

In the Thames the following articles are only a few examples of what have been found in dredging.

(1) Bronze head of statue of Roman Emperor Hadrian. (Hadrian's Wall) (A.D. 117-138). (This may be seen at the British Museum.)

(2) Tusks, teeth and bones of the Mammoth (several of these) now in South Kensington Museum.

(3) Ancient wrecks embedded in old channel.
(4) Purses thrown into the river by thieves when pursued by police.
(5) Glacial epoch shell fish (Nautilus Regalis). These shells are like the conch shell in shape but as large as a boy's head.
(6) Spears, bronze shields, and other implements dropped in river by Ancient Britons and Romans, B.C. and A.D., probably when engaged in combat at the fordable parts of the river.

As an indication of the changes which have followed dredging of harbours, Liverpool in 1860 was a half tide port only; to-day it is a full tide port: that is to say, ocean vessels may enter and leave at almost any state of the tide.

Similarly, at London the changes have been great and vessels may proceed up river to the largest docks 40 miles from sea without waiting for high tide.

Southampton, Glasgow, Bristol, the Tyne ports, Rotterdam, Amsterdam, Antwerp, Hamburg, the French ports from Calais to Toulon have particularly depended for their prosperity on dredging as part of the port improvements.

Although the signs and portents of Naval Architecture indicate increase of speed without a considerable advance in the depth of the ship of the immediate future, ships in some trades do shew a tendency to an increase in length and width, with an increase in depth.

This, coupled with the time-saving factors which deeper channels and harbours provide, indicate that dredging, which may literally make an ancient harbour into a modern one, will become of more and more importance in the days with which this generation are immediately concerned.

The relation of increased shipping trade to increased depth in a harbour was referred to in 1886 by Mr. Thomas Stevenson, P.R.S.E., in his work, *The Construction of Harbours*. He then pointed out that the commercial advantages are not proportional simply to the additional depth, but they increase

in a much higher ratio. He showed that using a certain formula of tonnage per ship to draft, that the capacity for trade of a channel 10 feet deep would be increased eight times if its depth be increased to 20 feet. Further, that in general the capacities for tonnage of different channels vary as the cubes of their depth.

The extent that these conclusions reached in 1886 may have proved correct require to be measured with modern considerations—the introduction of twin, triple, and/or quadruple screw vessels, which have assisted in the manoeuvring of vessels of large tonnage considerably, improvement of sharp bends in addition to depth, etc.

We have some remarkable conversions from ancient to modern conditions from dredging in ports as far apart as Natal and Fowey. In neither port are there any closed docks, the quays and berths having been improved by dredging during the last few decades to admit large vessels.

Recently during a discussion on the proposed Channel Tunnel a well-known naval architect reminded us that a tunnel must reach saturation point in respect of traffic, but that by progressive improvements of the cross-Channel harbours and vessels using them a very wide range of elasticity in traffic could be provided for—with a more definite financial horizon. Dredging would play a considerable part in any such scheme.

Engineers, marine officers, and harbour superintendents called upon to operate dredging plant for the development and maintenance of harbours, are usually faced with several problematic elements of importance in the operations.

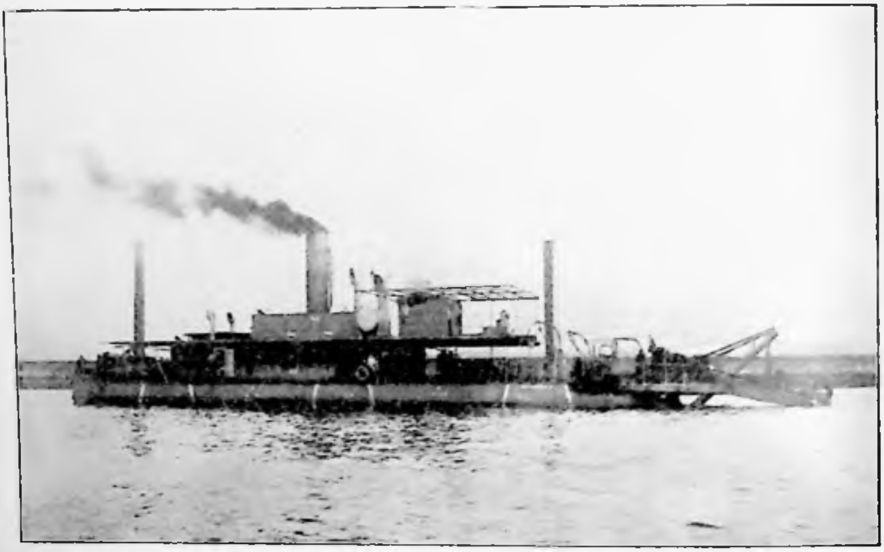
(1) Finance or cost.

(2) Proper type of plant for duty in hand.

(3) Method of disposal of dredgings.

Of these, costing may be defined as the proper disbursement of the financial appropriations and generally comes under five heads:

(1) Determination of true cost.



Dredger *Burdwan* built by Simons of Renfrew.
(*See page* 7.)

(2) Control of stocks to maintain supplies for works in progress.
(3) Provision of reliable basis for estimates.
(4) Valuation of work in progress.
(5) Provision of statistical information for guidance of management.

All engineering or industrial operations depend on the cost relation, and dredging is no exception to this fact. When any operation becomes what we term cost prohibitive a termination of the work or adjustment of the principles becomes necessary.

In dredging there are operations which are not visibly economic, being recurrent or so continuous as to be an annual charge on harbour accounts, but nevertheless essential to the life of the port.

If under such conditions costing may be merely limited to shew gains and losses owing to varying conditions of weather, stratification, etc., it serves a useful purpose.

There are many harbours with bars and other natural unavoidable encumbrances as the approaches to docks, quays, etc., which present the problem of constantly maintaining depths which cannot be economical, the shoals reverting to shallow type shortly after removal by dredger. Such dredging operations with their recurring expenditure are usually maintained for the well-being of the port to ensure some vital and indirect gain in transport. These operations thus appearing non-economic may be nevertheless justifiable from wider standpoints.

The policy of dredging harbours during the periods of prosperity of the port next comes to mind.

There are instances of channels and waterways having been regarded as of insufficient importance to warrant much expenditure. This applies with emphasis to estuaries, which with attention to ensure conservancy would preserve the life of the waterway.

Neglect to use part of the revenue for improvement or

proper maintenance has led to gradual deterioration of channel, followed by a fall in revenue from loss of shipping to a level precluding any improvement whatsoever. To this end, there is therefore the moral—that, while there is revenue, the principle should be to use it for maintaining the regimen of the harbour, it should be so utilised lest the day come when the trade has departed.

Referring now to physical conditions: There are ways and means of saving, by study of natural factors. The South African ports provide examples, for instance, of meteorological effects on cost of dredging. The South-Easter piles the sand up against the discharge of the rivers at the first outset of the gale. The river in 24 hours or less becomes gorged with upland water caused by rainfall from the same storm and its discharge subsequently scours the bar away. Occasionally the rainfall misses the catchment area and the bar remains to be dredged.

Connected therefore with the hydrographical study there is the meteorological, to determine frequency and duration of winds, prevalence of fog, visibility, season of greater and lesser rainfall all of which are important to dredging enterprise, especially in tropical countries.

The suitability of dredging plant may also be dictated in some measure by the weather (exposure to heavy seas is not uncommon), and there are consequently a large number of dredgers combining with seaworthiness the other essentials, depth and capacity.

Geological factors call for a knowledge of stratification. The laws under which local rock, chalk, or conglomerate may be found—the inclination of the strata to observe faults thus leading to the location of alluvium, sand, or gravel of the more modern river bed or "thalweg."

Hydrographical investigations should be directed to ascertain the situation and character of the existing channels, shoals, and banks; the rise and fall of the tides, direction, duration and velocity of the tidal streams, thus forming a complete survey of the existing conditions.

Computing a Datum for Soundings.—Primarily, a level is required for *all* dredging. To compute a datum level, therefore, if not provided by some fixed mark on shore becomes an early duty.

In the British Isles we are happily situated in respect of tidal level information, as the level of the Ordnance Survey or official land datum is directly related to mean sea level at the seaport of Liverpool and is transferable elsewhere by an existing network of co-related level or bench marks.

Depth to which dredging is carried may therefore be referred with facility to this level. Supplementary information can be readily obtained in Part I., 1928, of the abridged edition of the *Admiralty Tide Tables*, pp. 344-345, which shows for the British Isles and several continental seaports the relation between the land survey datum and

(1) Mean low water springs.
(2) Mean low water neaps.
(3) Mean tide level.
(4) Mean high water neaps.
(5) Mean high water springs, at certain places.

Together with the Authority for observations, constants, predictions, and other useful matter, shewn over leaf.

Chart datum corresponds to the zero of the predictions in all cases except at Londonderry, where chart datum is 4·12 ft. above Ordnance datum, and comparison between Ordnance datum and zero of predictions is not exactly known.

The zeros of the predictions at St. Helier, Londonderry and Galway have not been connected with Ordnance datum. At St. Helier zero is 38·66 ft. below a bench mark cut in the bed rock close to the east end of the parapet of Victoria pier; zero at Londonderry has not been connected with any fixed mark; zero at Galway is 20·00 ft. below the top of Nimmo pier.

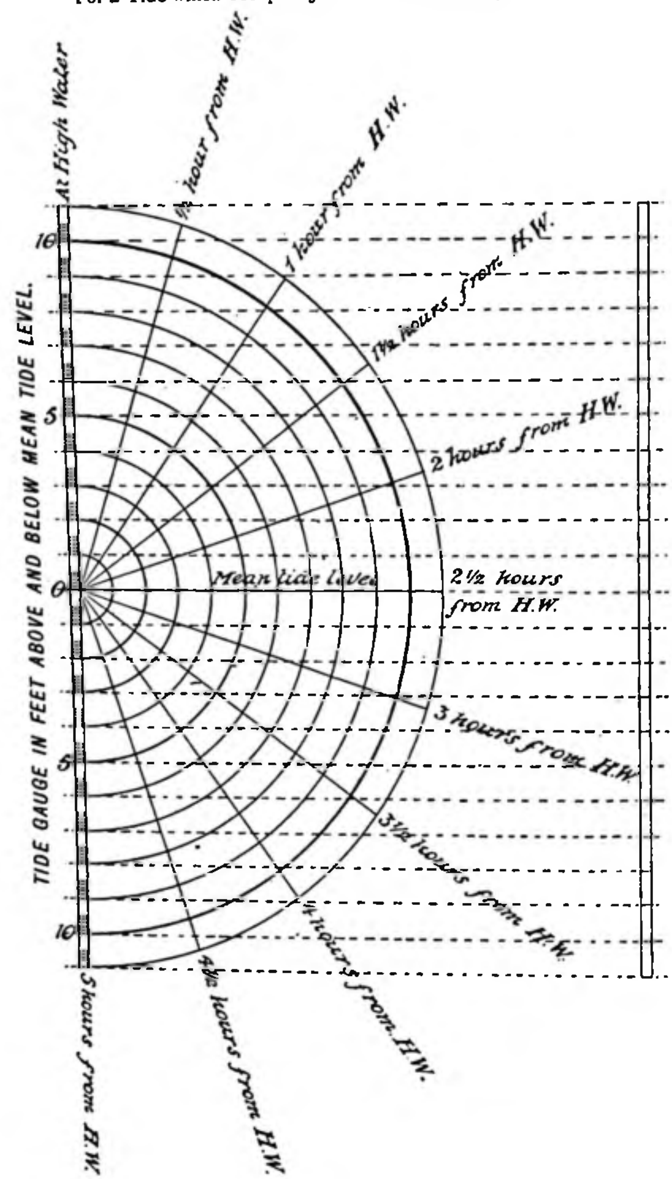
Zero at Ponta Delgada is 9·25 ft. below a bench mark on the breakwater near the tide gauge.

(*a*) Land Survey Datum is, in Great Britain and

TIDAL DIAGRAMS.

Tidal Diagram No. I.

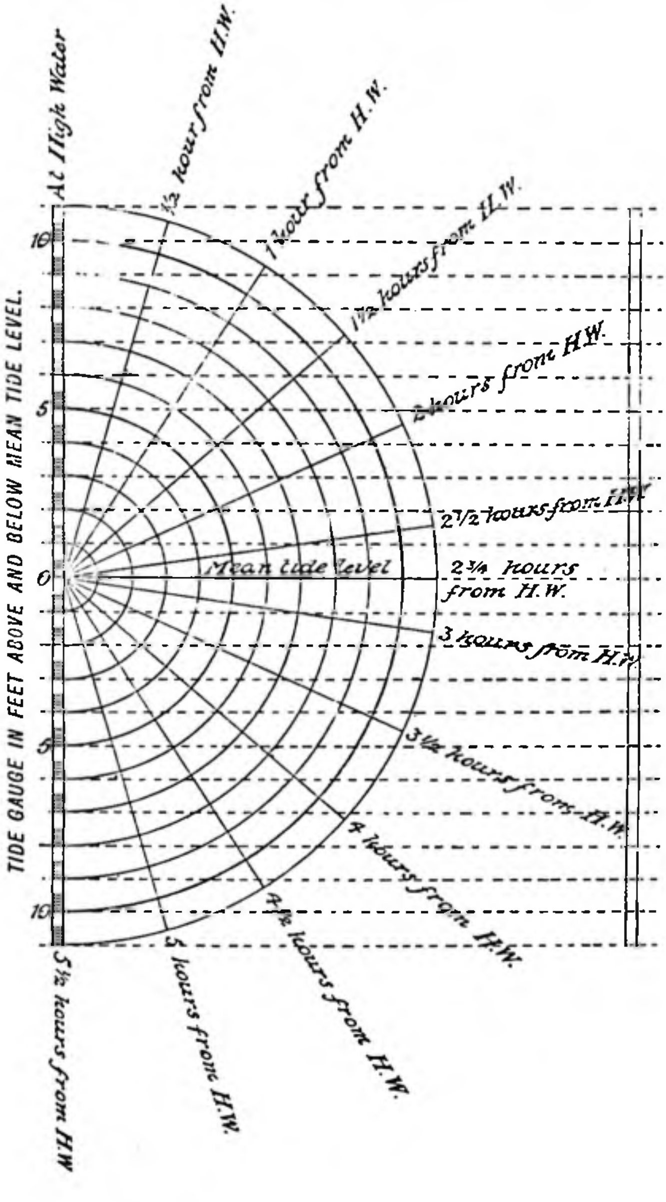
For a Tide which occupies 5 hours in either rising or falling.



TIDAL DIAGRAMS.

TIDAL DIAGRAM No. II.

For a Tide which occupies $5\frac{1}{2}$ hours in either rising or falling.



TIDE LEVELS AND DATUMS—STANDARD PORTS IN EUROPE.

Levels referred to the Zeros of the Predictions, Authority for Predictions, Method of Predicting, etc.

Standard Port.	Land Survey Datum (*a*)	Mean Low Water Springs.	Mean Low Water Neaps.	Mean Tide Level.	Mean High Water Neaps.	Mean High Water Springs.	Authority for (*b*) Observations.	Constants.	Predictions.	Method of Predicting (*c*)	Years of Tidal Observations. (*d*).
	F.	F.	F.	F.	F.	F.					
Devonport	+8·42	+0·18	+4·60	+8·15	+12·25	+15·70	A.	H.D.	H.D.	Eq.	1862
Portland	+2·08	0·00	+2·42	+3·21	+4·17	+6·75	H.D.	T.I.	T.I.	H.C.	1923–24
Southampton	+6·75	+0·35	+3·23	+7·04	+11·42	+13·16	P.A.	T.I.	T.I.	H.C.	1924
Portsmouth	+6·17	+0·15	+3·94	+6·89	+10·40	+13·10	A.	H.D.	H.T.	Eq.	1914
Dover	+8·42	+0·05	+4·19	+9·34	+14·61	+18·65	A.	H.D.	H.D.	Eq.	1915–16
Sheerness	+6·87	+0·80	+3·38	+8·83	+14·03	+17·08	A.	H.D.	H.D.	Eq.	1913
Chatham	+7·38	+0·62	+3·46	+9·38	+15·11	+18·41	A.	H.D.	H.D.	Diff.	1913
London	+8·47	+1·42	+3·68	+11·51	+18·65	+22·30	P.A.	T.I.	T.I.	H.C.	1925
Harwich	+4·59	+1·05	+2·86	+6·79	+10·52	+12·60	H.D.	H.D.	H.D.	Eq.	1902
Immingham	+9·25	+1·42	+6·28	+11·35	+16·53	+21·17	P.A.	Rob.	Rob.	H.	1912
River Tees	+8·40	+1·50	+5·35	+8·96	+12·78	+16·18	P.A.	H.D.	H.D.	Eq.	1897
River Tyne	+7·08	+0·78	+4·20	+7·64	+11·15	+14·50	P.A.	H.D.	H.D.	Eq.	1916
Leith	+9·25	+1·88	+6·08	+10·02	+14·34	+17·98	H.D.	H.D.	H.D.	Eq.	1909
Rosyth	+8·75	+1·20	+5·35	+9·47	+13·90	+17·50	A.	H.D.	H.D.	Eq.	1918–19
Invergordon	+6·75	+1·90	+5·00	+7·83	+10·75	+13·62	H.D.	H.D.	H.D.	Eq.	1916
Stromness	+5·31	+0·68	+3·65	+5·56	+7·48	+10·28	H.D.	H.D.	H.D.	Eq.	1911–12
Oban	+6·99	+1·13	+4·35	+6·25	+8·05	+11·58	H.D.	H.D.	H.D.	Eq.	1912–13
Greenock	+6·08	+0·29	+2·32	+5·34	+8·40	+10·31	P.A.	H.D.	H.D.	Eq.	1912–13
Liverpool	+14·66	+1·65	+7·56	+15·19	+22·85	+28·70	P.A.	T.I.	T.I.	H.C.	11 years 1857–1924
Holyhead	+8·58	+0·20	+4·24	+8·25	+12·50	+16·08	H.D.	H.D.	H.D.	Eq.	1908–09
Pembroke Dock	+11·82	+1·89	+7·54	+12·17	+16·97	+22·33	H.D.	H.D.	H.D.	Eq.	1892
Swansea (Mumbles lighthouse)	+14·00	+0·72	+8·28	+14·65	+21·08	+28·50	H.D.	H.D.	H.D.	L.	1858–61
Avonmouth	+19·83	+1·46	+10·12	+21·13	+31·15	+41·78	P.A.	T.I.	T.I.	H.C.	1924–25
Kingstown	−1·75	+0·75	+3·40	+6·42	+9·80	+11·72	P.A.	H.D.	H.D.	Eq.	1908–09
Belfast	−2·40	+1·59	+3·14	+6·44	+9·69	+11·08	P.A.	H.D.	H.D.	Eq.	1913
Londonderry	—	0·00	+1·80	+3·80	+5·61	+7·72	H.D.	H.D.	H.D.	L.	1853–56
Galway	+20·00	+0·77	+4·87	+8·23	+11·84	+15·73	H.D.	H.D.	H.D.	Eq.	1845–46
Queenstown	−1·92	+0·18	+2·54	+6·15	+9·50	+12·15	H.D.	H.D.	H.D.	Eq.	1907
Kem	—	+1·25	+2·17	+3·61	+5·05	+5·97	Rus.	Rus.	Rob.	H.	1910
Ekaterinskaya	—	+2·23	+4·41	+7·05	+9.69	+11·87	Rus.	Rus.	Rob.	H.	1907
Heligoland	+5·76	0·00	+1·35	+4·30	+7·26	+8·57	G.	G.	G.	Diff.	—
Cuxhaven	+5·61	0·00	+1·09	+5·15	+9·06	+10·44	G.	G.	G.	Diff.	—
Wilhelmshaven	+7·35	0·00	+1·58	+6·55	+11·62	+12·99	G.	G.	G.	—	—
Hook of Holland	+2·69	+0·63	+0·93	+3·41	+5·52	+6·54	N.	N.	N.	—	—
Flushing	+8·20	+0·75	+2·78	+7·75	+12·29	+15·04	N.	N.	N.	—	—
Dunkerque	+7·94	+2·15	+4·79	+10·54	+16·00	+19·24	F.	H.D.	H.D.	Diff.	—
Havre	+14·08	+3·22	+8·27	+14·46	+21·16	+25·20	F.	F.	H.D.	Diff.	—
St. Helier	+38·66	+2·76	+11·47	+18·89	+26·04	+35·26	H.D.	H.D.	H.D.	Eq.	1903
Brest	+11·12	+4·59	+9·84	+14·60	+19·36	+24·61	F.	F.	F.	—	—
Cordouan	+7·71	+2·95	+6·56	+9·76	+13·12	+16·40	F.	F.	H.D.	Diff.	—
Lisbon (Cascais)	—	+1·40	+3·75	+6·10	+8·40	+10·80	P.	P.	Rob.	H.	1914
Gibraltar	+1·29	+0·52	+1·50	+2·17	+2·90	+3·65	A.	Rob.	Rob.	H.	1 year
Ponta Delgada	+9·25	+0·62	+1·78	+2·75	+3·73	+4·88	M.A.	T.I.	T.I.	H.	1924

Ireland, *Ordnance datum*; in Germany, *Normalnull*; in the Netherlands, *N.A.P.*; in France, *zero du nivellement Bourdaloue*; at Gibraltar, *Ordnance datum.* No general land survey datum is in use in Russia.

Ordnance datum in Great Britain is approximately mean sea level at Liverpool, the level being calculated from one month's tidal observations 1844. True mean sea level at Liverpool, calculated from eight years' tidal observations 1857-60, 1867-70, and 1902, is 0·34 ft. above Ordnance datum.

NOTE.—It having been found that errors existed in the levelling of Great Britain, a new levelling, in which mean sea level at Newlyn computed from six years' tides 1915-21, is used as datum, was commenced in 1912. The full results of this levelling are not yet available, and references to Ordnance datum in Table VII. are therefore to the old level.

Ordnance datum in Ireland is approximately the level of low water spring tides in Dublin Bay, and is the level of low water on 8th April, 1837. The true mean level of low water spring tides in Dublin Bay is 2·50 ft. above Ordnance datum.

Ordnance datum in Ireland has not been geodetically connected with Ordnance datum in Great Britain. If, however, the mean tide levels at Kingstown and Holyhead are assumed to be the same relatively to Ordnance datum in Great Britain, then, from two years' simultaneous automatic tide-gauge records at Holyhead and Kingstown, Ordnance datum in Ireland is 8·46ft. below Ordnance datum in Great Britain.

Ordnance datum in Great Britain is 4·67 ft. above the sill of the Old Dock at Liverpool; this dock is no longer in existence, but the level of the sill is preserved on the river face of the centre pier of the entrance to Canning Halftide Dock.

Ordnance datum in Ireland is 20·90 ft. below a bench mark on the base course, under the south window, of Poolbeg Lighthouse.

Normalnull in Germany is approximately the mean level of the North Sea on the German coast.

A.P. (Amsterdamsch Peil) is the level at which the water of the Zuider Zee was formerly allowed to enter the canals at

Amsterdam; this level was extended over the country and became the land survey datum in the Netherlands. Errors having been detected in the extension, a new levelling was undertaken in 1870 and the new level of the datum is referred to as Nauwheurigheids Amsterdamsch Peil (*N.A.P.*)

Zero du nivellement Bourdaloue in France and *Ordnance datum* at Gibraltar are arbitrary levels which have no connection with sea level.

(*b*) and (*c*). *Abbreviations*—

H.D.—Hydrographic Department.
P.A.—Local Port Authority.
G.—Deutschen Seewarte.
M.A.—Service Meteorologique des Acores.
T.I.—Tidal Institute, University of Liverpool.
A.—Admiralty.
Rus.—Russian Tide Tables.
N.—Netherlands, Department van Waterstaat.
F.—Service Hydrographique, Ministere de la Marine, Paris.
P.—Commissao de Hidrografia, Ministerio da Marinha, Lisbon.
Rob.—Messrs. Edward Roberts & Son.
Eq.—Equation Method.
L.—Lubbock's Method.
H.—Harmonic Method.
H.C.—Harmonic Method with corrections.
Diff.—Method of variable differences.

(*d*) Where the years of tidal observations are in italics the observations do not cover the whole of the years given.

Where no official information exists, it becomes necessary to "*compute a datum.*"

Computing or determining a datum especially *before* extensive dredging is an important matter for the reason that after the dredging improvement has been completed in narrow waterways the tidal levels may no longer be those existing before the commencement of dredging.

The tidal survey requires therefore to be accurate and

complete, and the changes referred to not only apply to tidal level but also to the time of occurrence of high and low tide, the removal of shoals having the effect of accelerating the influx and efflux of the tidal stream, and ultimately the duration of the tide. During this tidal transition period careful records should be kept.

Approximate Methods.—If we are out of touch with Ordnance Survey bench marks a good determination of *local mean sea level* may be obtained by what is termed the "Challenger" method in less than two days.

Take a moderate number of observations properly distributed so as to subdivide both solar and lunar days into not less than three equal parts.

Suppose, for example, we choose 8-hour intervals, both solar and lunar. Take a lunar day of 24 hours 48 minutes of solar time, which is near enough and convenient for division, choosing any convenient hour for commencing to observe the height of the water at the following times reckoned from the commencement:

h	m	h	m	h	m
0	0	8	0	16	0
8	16	16	16	24	16
16	32	24	32	32	32

The observations may be regarded as forming three groups of three each, the number of each group being separated by 8 hours solar and lunar, while one group is separated from the next by 8 hours lunar or solar. In the mean of the nine results the lunar and solar semidiurnal and diurnal inequalities are all four eliminated.

Nine is the smallest number of observations which can form a complete series. If the solar day be divided into m and the lunar into n equal parts, when m and n must both be greater than 2, there will be mn observations in the series; and if either m or n be a multiple of 3, or of a larger number, the whole series may be divided into two or more series having no observation in common and each complete in itself.

The accuracy of the method can thus be tested by

comparing the means obtained from the separate sub-series of which the whole is made up.

To compute a rigorous tidal datum requires tidal observations extending over a long period in order that seasonal changes in level, and changes of longer period in both level and range, may be eliminated. Close approximation however may be obtained from one year's tides, for the important seasonal variation which may amount to as much as about $+3$ ft. is then eliminated and longer period changes are small and insignificant. As a standard method of obtaining the average lowest low water, the averaging of the lowest tide in each calendar month for a solar year is suggested; another method would be to average the lowest tide in each of twelve lunar periods, using synodic, tropical or anomalistic months according to the type of tide.

Synodic—When the variation from springs to neaps, in accord with the moon's phases, is the predominant feature.

Anomalistic—When the greatest variation is in accord with the moon's distance from perigee to apogee, *i.e.* closer or farther from the earth.

Declinational Type—Characterised by diurnal inequality which is so pronounced as to be the leading variation.

Having selected the tidal datum and computed the value, there come other important calculations and observations to define the level of the tide.

As the bed of a channel rises towards the source so does the tidal range decrease, until we proceed so far up the tidal stream as to be beyond the rise and fall of the tide. For instance, in the estuarial Port of London, at Richmond on Thames the range of the tide is considerably less than at London Bridge.

At London Bridge the tidal range is greatest, as this section lies in pocket of maximum tidal oscillation or near the middle of the Thames lower flood plain.

At Southend-on-Sea the range is less than at London Bridge—as it approaches sea level conditions.

In dredging the lesson to be learnt from the tidal gradient is that mean tide level differs according to locality and depends on the situation entirely for its value.

A horizontal zero such as Whangpo horizontal zero or Trinity high water does not imply that the slope of the waterway is horizontal except at the point and place of the index of reference.

Changes of a striking character have taken place in tidal regime consequent on dredging, notably on the Clyde, Tyne, and Thames. The following changes have taken place in the Clyde waterway consequent on dredging and conservancy of channel.

RANGE OF SPRING TIDES.

1927 Glasgow Harbour=$13\frac{1}{2}$ feet. 1834=7 feet.

In the Port of London the change at low water on all tides has occurred, thus increasing the range, and is also noticeable at the high levels. The deepening of the tideway below London Bridge has had the natural effect of draining off the water into the pools thus found by dredging, with a consequent annual addition to the number of tides falling below a certain low water level, in the upper reaches.

The tabulated results given below shew the progression in comparison with cubic yards of river dredgings removed in the successive years 1913-1923, datum 21 feet below Trinity high water mark, which is the zero of soundings for that section of the tideway.

EFFECT OF DREDGING ON FALL OF TIDE AT LONDON BRIDGE.

Year	Fall below datum	all within 6″ of datum	Cubic Yards removed from River Thames.			
			Channel dredging	Special tay-bye dredging	Wharf and other dredging	Total
1913	1	7	4,643,423	521,390	—	5,164,813
1914	3	14	2,698,837	373,840	—	3,072,677
1915	0	7	1,373,041	292,144	—	1,665,185
1916	3	14	462,619	207,292	—	669,911
1917	3	17	20,143	196,243	14,862	231,248
1918	7	24	4,065	140,545	18,304	162,914
1919	1	10	621,034	131,031	5,074	757,139
1920	3	20	971,294	269,186	80,452	1,320,932
1921	11	33	1,937,690	265,091	71,300	2,274,081
1922	24	47	2,791,875	365,434	1,412	3,158,721
1923	26	66	3,095,484	469,644	10,111	3,575,239
11 years	82	259	18,619,505	3,231,840	201,515	22,052,860

CHAPTER II.

The Marine Surveyor's Implements—Triangulation and Preparation of Charts or Plans—Tide Gauges—Determination of Currents and River Gauging—Current Meters—Relation of Dredged Curves to the Turning Circle of Large Ships.

The Marine Surveyor's Implements.—The implements used by marine surveyors are many; we will enumerate the principal ones here. Theodolite; drawing board; brass or metal straight-edge with scale; beam compasses for plotting long radii; sextants for sounding work; lead line; station pointer; 10 ft. pole; steel tape (50 feet) or surveyor's land chain; dumpy or handy level; level staff for levelling.

The Theodolite is essential in triangulation work and can be made to serve as a level if required by careful manipulation of the bubble level and exact reading. It may also be used when sounding out a bay or river by erecting it at a station on shore where by prearranged signal a line is read through the portion of the boat as it moves along the cross section which is being sounded. By this method the officer or engineer in the boat need only take one angle and note time of signal with depth obtained. The observer at the theodolite provides the second check or angle. Watches should be synchronised beforehand.

Sounding Sextants are now usually cut to the nearest minute so that the observer can read ° degrees and ′ minutes quickly and of sufficient accuracy for fixing position of a boat or dredger. Thus the white metal insertion on the arc used in navigation is not necessary.

Sounding Leads.—To ascertain depth, sounding leads from 7 to 14 lbs. weight for hand manipulation and slightly

flattened at base when used in a soft mud bottom are usually employed.

If accuracy to inches is required then the lines should be made of manganese bronze wire, which is strong, does not readily change in length, and does not kink in the way that fine galvanised wire will do.

This leadsman's wire should have swivels at top and bottom and is usually marked in feet or metrical subdivisions as required. The size of wire we have found most suitable consists of six strands, each strand having 12 wires of 0·0148″ diameter.

Sounding Pole.—For extensive inshore work such as repeated examinations of dock entrances the sounding pole is invaluable. It is usually marked in feet.

The Sutcliff Sounding Machine.—Also of convenience in shallow water inshore sounding such as dock entrance examination. It consists of a wheel operated by the surveyor; to this wheel both plummet line (the vertical) and control (the hypotenuse) line are attached. The depth can be read off a dial which records the revolutions or depth. When skimming over a flat area the lead is kept submerged, being raised a turn or two of the wheel and dropped again.

Snapper Lead.—For ascertaining the nature of the river or seabed *before dredging* the snapper lead is invaluable. We show a sketch of this implement which has jaws closed by a strong spring which are set open on each occasion a sample is required. A small wire winch with a band brake is the best machine for this work.

Station Pointer.—This instrument is used for placing two angles simultaneously on a plan or chart. It has a central point where the angles intersect to enable the surveyor to make a pencil mark to indicate the position thus transferred.

This instrument is of particular value on a dredger working by sextant angles to obtain position as the work progresses. We have found it possible to dredge to a high degree of precision by such methods.

Both station pointers and sextants should be adjusted during and after use, otherwise an index error is liable to creep in which affects accuracy.

We favour the 8-inch diameter circle station pointer. This instrument is not too large for small plans and is capable of use on large plans with the extension legs fitted.

The arc is cut to 30 minute divisions and vernier to 1 minute divisions.

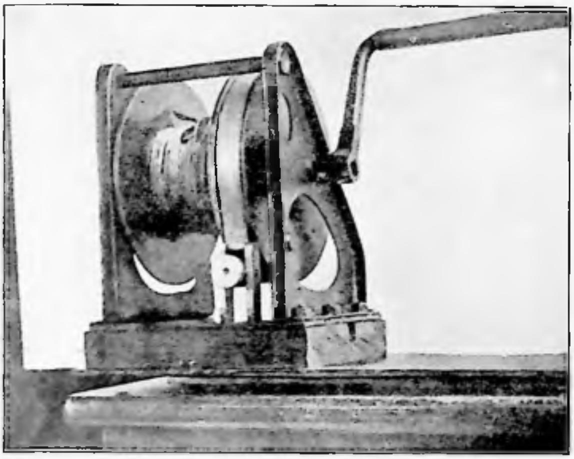
Snapper Lead.

Sinkers for sounding machines. Snapper fitted with spring slip hook for disengaging the 50-lb. cast-iron sinker. The jaws of the snappers are held open until the bottom is struck, when they are closed by a powerful spring, shutting in a specimen of the bottom.

Measuring Wire Tape and Chain.—In addition to these implements a boat fitted with the type of drum shown is almost essential for measuring distances across water surface, etc. A galvanised wire kept well greased is the best arrangement. It should be marked every 10 feet (or less if required), with special tags every 50 feet to assist in the immediate identification of distance measured. These 50 ft. tags should vary in colour: 50 blue, 100 red, 150 green, 200 yellow, 250 blue, and repeated, all hundreds over 200 being yellow.

Rangefinders.—Sometimes used for important distance ranging in surveys, but are expensive. We do not propose to enlarge on their use here.

Survey Launches and Boats.—The most suitable floating plant for survey work in harbour waters is a small motor boat with an engine which is capable of being throttled or geared down during soundings, which usually require a slow speed. This launch should be capable of towing a four-oared boat in a seaway and therefore should be of robust construction.



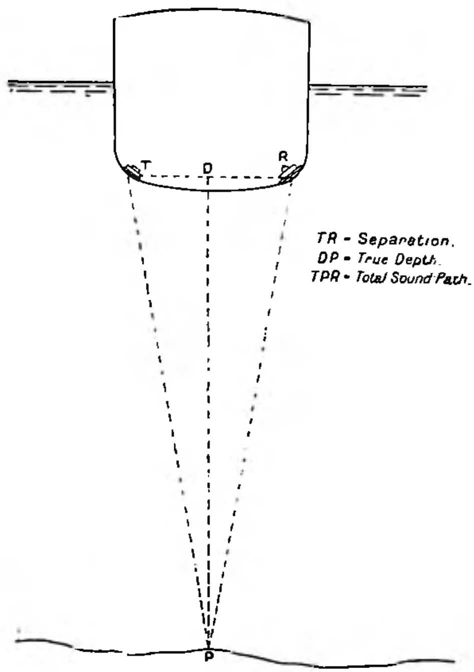
Type of hand reel used for measuring off-shore distances by wire from boats during surveys of dredged areas.

Small boats are now fitted with outboard motors of considerable power; being detachable they have the advantage that the boat can be readily converted into a rowing boat if necessary.

The Echo Sounding Machine.—The modern survey vessel is now fitted with an echo sounder which for dredging purposes will be of the shallow water type.

Principles Employed in Echo Sounding.—A sound is transmitted from the hull of the ship. This sound wave travels outwards in all directions, and, on striking the bottom is reflected as an echo. The echo is picked up by a receiver fixed to another part of the hull and is heard in the telephones.

The time taken for the sound to travel from the ship to the bottom and back again is a measure of the depth of water. As this time is short it is necessary to be able to measure it with accuracy. If the position of the depth recorder is accepted when the first increase of sound is heard, then you have the reading of the shortest path taken by the sound wave between the transmitter, the bottom and the receiver.



Shallow Water Sounding Gear.

The time taken by the sound wave to travel to the bottom and back is converted into echo feet, and is read off directly on the scale, which gives the depth of water in feet.

N.B.—Echo feet must be remembered as the double journey of the sound waves.

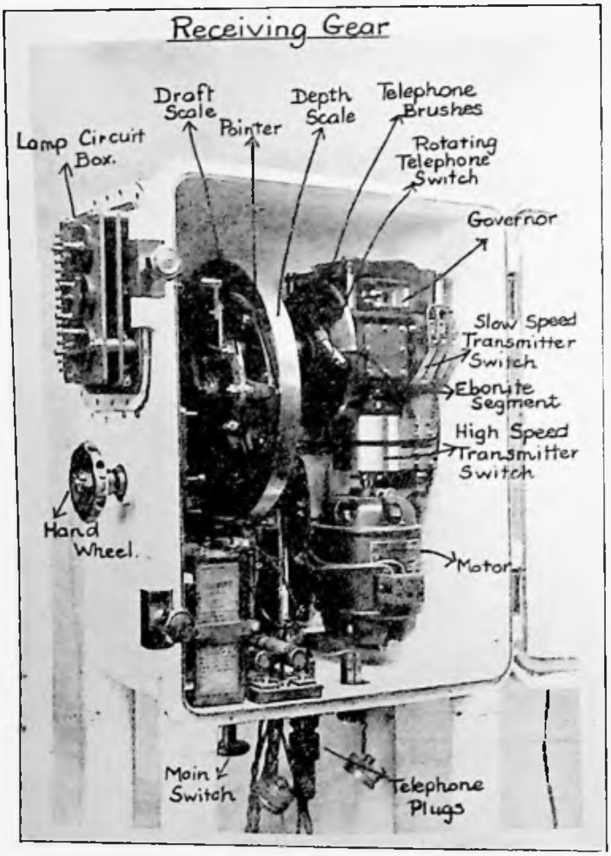
For the examination of dredged areas where the dredger has probably left hummocks due to irregular stratification, we have found the echo sounding machine invaluable. In

going over an area where we anticipated such conditions the Echo sounder located the shoal heads much more efficiently than the leadsman was able to do with the hand lead line. The protuberance effects were heard clearly on the echo, but the minuteness of the difference between hand lead readings and echo made acceptance of the echo depths dubious. The ground was therefore surveyed more closely with a hand lead and the exactness of the Echo sounder confirmed. These depths varied from 28 to 36 feet during a tidal range of approximately 18 feet.

The Port of London Authority has recently taken an interesting step in connection with its surveying operations. It has been the custom hitherto to ascertain the depth of water in various parts of the river by means of sounding with the lead. The large area over which the Authority has jurisdiction entails a considerable amount of work in this direction. In some parts of the river the depth is taken not more than once every five years, but in other parts, where changes are continuous, and where the necessity for keeping a deep channel is essential to permit of large liners navigating the channel, soundings have to be made frequently. The Port of London Authority has installed an acoustic sounding machine in its survey vessel *St. Katherine*. Thus the old method of employing manual labour has been considerably reduced, but the lead is still employed in shallow waters.

The apparatus is not new, and that which has now been adopted by the P.L.A. is a British patent. The idea of ascertaining the depth of water by means of sound was first employed in Newfoundland in 1912. The present apparatus, which differs considerably from that originally introduced, was tested by the Admiralty for about two years, and some of the experiments were carried out in the Thames Estuary. That was during 1927, and the success which attended the operations induced the P.L.A. to give serious consideration to the proposals to adopt the new method as an auxiliary to the old-fashioned way already in force. The area in Sea Reach

alone, which is surveyed every year, is about 100 square miles, and so important is this part of the river from the navigational point of view that it is essential that slight changes in the bed of the river should be noted. In water of a depth of from 3 fathoms to 15 fathoms protuberances and obstructions,



Echo Gear.

such as abandoned wrecks, are detected much more readily by means of the echo sounder than by the old-fashioned means, as the echo has the property of searching out and returning a note which indicates the obstruction, whereas with the lead line and plummet it is quite possible for the obstruction to remain

undiscovered, though the surrounding bed of the river may have been tested pretty thoroughly. The *St. Katherine* is a boat of a shallow draught type which can operate in 12 ft. of water.

It should be added that the surveys in the majority of the reaches take place annually, but in some twice annually, as in Barking Reach, where special dredging is necessary in order to permit of the big liners approaching King George Dock in safety. The whole of the surveying takes place during daylight, the electric power for the motor of the echo-sounding machine being provided by the ship's dynamo, which at night is employed to illuminate the vessel.

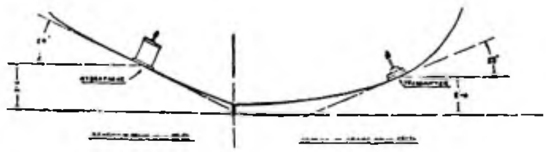
The advantages of the echo sounding apparatus over the manual method may be summarised as follows: (1) The frequency of soundings at any given speed of ship is increased in the ratio of ten to one when compared with hand plummet line sounding. (2) At all speeds the frequency is so much greater than by manual sounding that a more thorough examination is made. (3) The machine responds readily when an obstruction such as a protuberant wreck is encountered, the echo searching out and indicating the elevation in a manner impossible by vertical or plummet sounding. (4) Soundings may be taken in rough weather. This is not possible with hand sounding owing to the water surface being the level of measurement. (5) The foregoing factors considerably reduce the time of survey over a given area, thus extending the scope of operation of the survey ship.

The machine has been patented by the Admiralty, and is manufactured by Messrs. Henry Hughes & Son, Ltd., of Fenchurch St. It has been already fitted in an increasing number of vessels. The apparatus can be used in three forms. In the first it is adapted especially for employment in water up to a depth of 135 fathoms; the second is used principally for trawler work and by submarines, and has a range of 400 fathoms; and the third is principally adapted for cable and survey ships, as well as for passenger liners, for use at a depth up to 4500 fathoms.

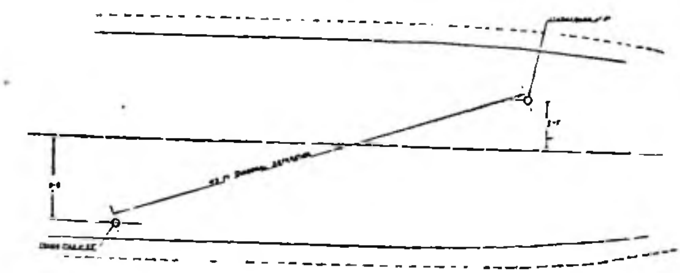
Survey Vessels.—The future of echo sounding is so certain that, now the loud speaker has been successfully introduced, in addition to headphones, it is possible to produce an amplifier which will produce a loud signal on the bridge the moment a shallow depth is reached, thus providing a danger or warning signal.

For river or harbour work this is invaluable, as up to 20 or 30 fathoms the amplification of the echo can be sufficiently obtained by a three-valve set without any water noise or acoustic atmospherics; this gives a remarkably clear and convenient means of detecting the gradual slope of the bottom over which the ship is moving.

Remarkable accuracy in shallow depths can be obtained; the error at depths of 3 to 4 fathoms cannot be more than 1 foot and, as the depth increases, this accuracy up to, say, 15 to 20 fathoms can become greater. Readings have been taken to 6 inches at 10 to 15 fathoms depths on the *St. Katherine*, which is fitted with this shallow water echo sounder.

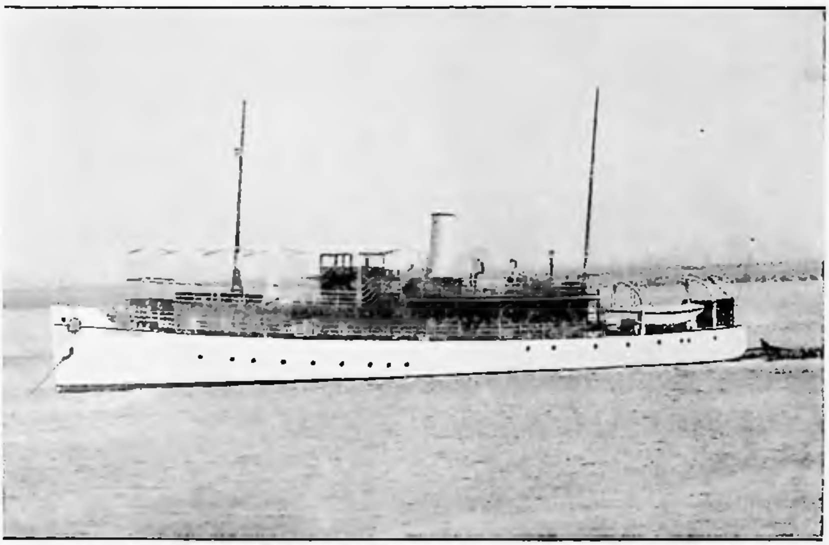


P.L.A. *St. Katherine.*



Triangulation.—Surveys are necessary for dredging and the basis of all good survey work is accuracy. Accuracy can only be obtained by having in our possession a survey sheet of an area to be dredged on as large a scale as possible,

with due regard to convenience. When the area is small such as a dock entrance the layout of the pierheads from the engineering plans will provide an efficient sheet for working, supplemented by some actual measurements in the field to ensure that the dimensions on the plan are actually correct. For wider areas triangulation will be necessary, a typical example of which is shown on the diagram herewith. Much depends on whether the stations are intervisible in the construction of the triangulation sheet, how the base is obtained,



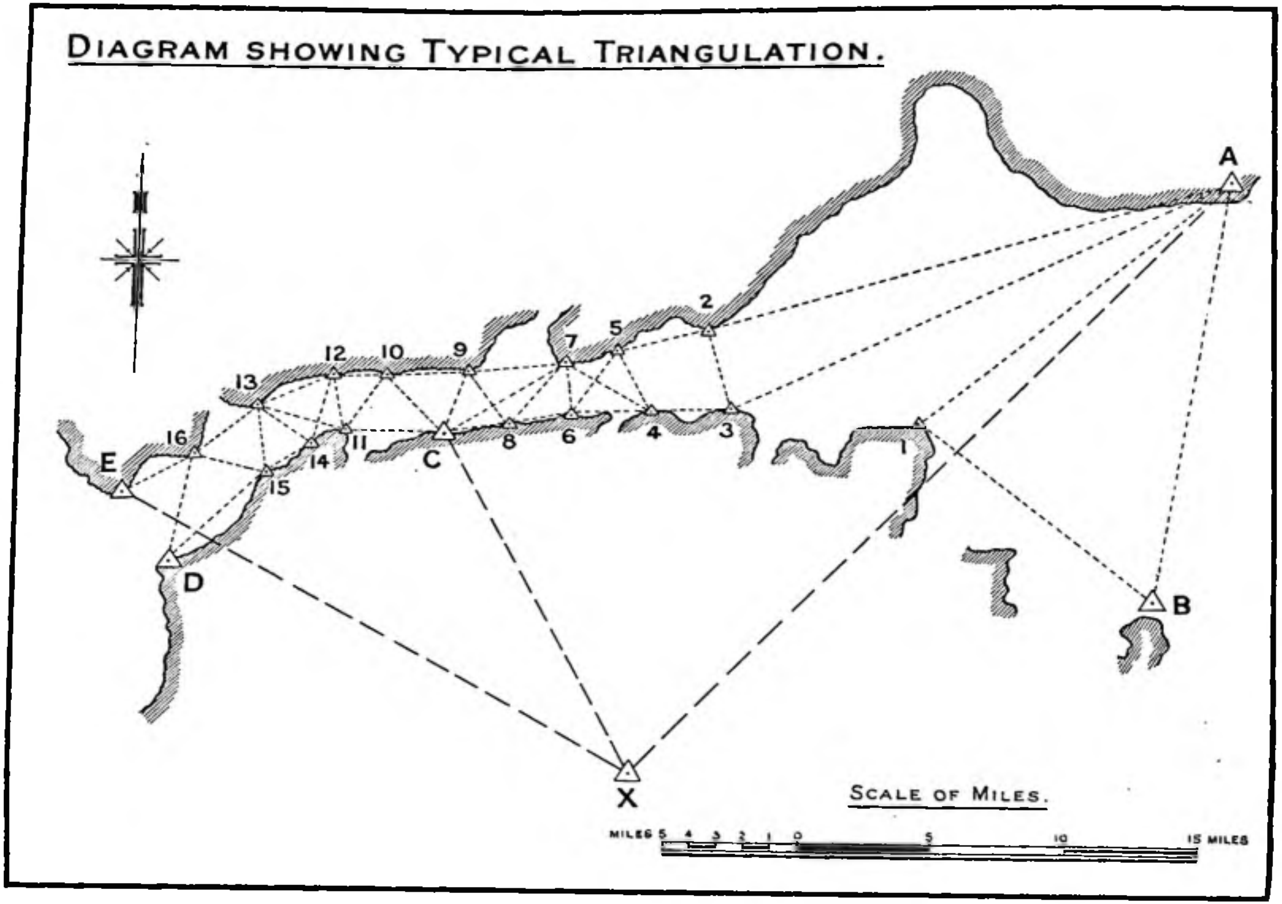
P.L.A. *St. Katherine.*

etc. If a base is accepted from an Ordnance sheet measurement, then at some stage of the triangulation opportunity should be taken to check one "side" if possible by tape measurement on the field.

Triangulation may, therefore, be constructed or adapted. The possession of an old triangulation is valuable; this can be checked and the supplementary matter for use in a special survey added. Triangulation can also be extended seawards or landwards with little extra labour to cover other areas.

In certain cases the use of co-ordinates such as are employed

DIAGRAM SHOWING TYPICAL TRIANGULATION.



by the British Admiralty surveyors from the Ordnance Survey renders it possible to cover large areas—the frame work being "calculated" and observation work therefore reduced to a minimum. For complete instructions, reference should be made to *Tables for Determining Geodetic Positions* (*Latitudes* 0° *to* 65°), *together with Methods of Using Co-ordinates*, by John A. Atherton, of the Hydrographic Department, Admiralty. (H.D. No. 243.)

In using these co-ordinates, a small portion of the earth under consideration is taken as a plane surface. Through one station—termed the point of origin—the meridian line is regarded as a zero line. To this zero line perpendiculars are drawn from other stations. These perpendiculars are the east and west co-ordinates, and the distances from the point of origin to the intersections of these perpendiculars with the meridian are the north and south co-ordinates. In great Britain and Ireland co-ordinates are given from a point of origin in each county, and therefore the co-ordinates for any particular survey may be given from more than one origin.

The geodetic position of the origin for each set of co-ordinates must be used for these co-ordinates. Co-ordinates from different points of origin can be combined by obtaining the geodetic position of each station by means of section (*e*) and using these positions to obtain the bearing and distance from one to the other. (*See* fig. 1.)

It is often convenient, in order to assist plotting by angles when the Ordnance trig. stations are not relatively well placed for the purpose, to select an imaginary suitable point and give it co-ordinates (to be obtained by rough measurement on a 6-inch Ordnance map). The angles at this point between all the Ordnance trig. stations may then be calculated and the point itself be used as if it had been an actual trig. station. (*See* fig. 2.)

Charts.—The advantages of large scale hydrographic charts are apt to obscure their inherent limitations.

Large plans depict Nature more accurately than small

scales but limit the plan of horizon. To portray a harbour on a scale which will not render the chart unwieldly, one finds that 12 inches to the nautical mile a sufficiently representative factor. Thus we have to consider expediency in fixing the scale of dredging surveys in harbours. A common scale for sounding plans at dock works used in dredging is 100 feet to 1 inch—or even as large as 88 feet to 1 inch.

Whatever the scale, the distance between the soundings is most important.

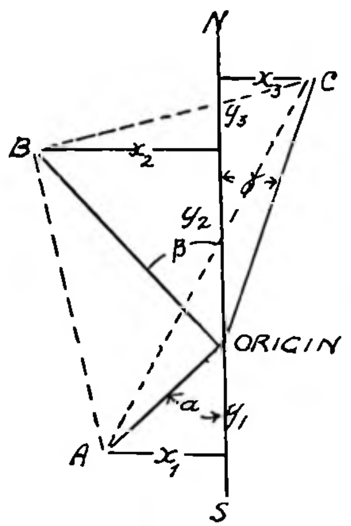


Fig. 1.

Triangulation from point of origin by co-ordinates (figure in pecked line).

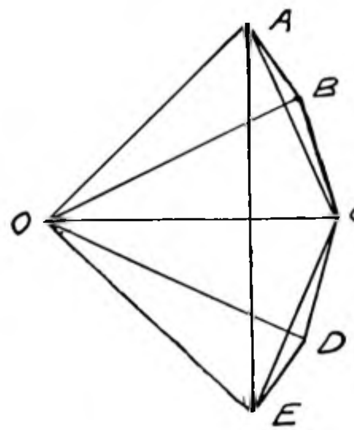


Fig. 2.

False origin station with calculated positions *A B C D E.*

The larger the scale the greater the accuracy will be in estimating the cube yards to be removed, by dredging.

Introductory to British Sailing Directions, there exist a warning as to the limits of legibility of soundings and an illustration of the number of soundings it is possible to shew clearly on a square inch of paper. This demonstrates that with small but legible figuring 100 soundings to the square inch can be shewn.

Consequently on a scale of 6 inches to the statute mile

or 880 feet to the inch, each subdivision or sounding will occupy or represent an area of 860·4 square yards. Where the scale is 25·344 to the mile or 208·33 feet to 1 inch, an area of 48·2 square yards covers one sounding, a considerable increase in accuracy of configuration.

16	15	15	13	13	14	12	11	10	9
14	15	14	14	13	13	12	11	9	8
15	15	14	17	16	14	13	10	10	9
16	16	17	18	16	12	11	8½	9	10
18	17	15	12	9	7½	7¾	7½	9	10
19	16	12	9	5½	4½	5½	6¼	8½	9
22	19	16	10	3¾	5¼	6¼	7½	8½	10
20	16	12	7½	5¼	6¼	6¼	7¼	8½	10
18	15	11	9	7½	7	7½	8½	10	11
20	17	14	11	12	10	9	10	11	13

Legibility of Soundings.

This arrangement means a close arrangement of soundings, whereas in actual practice chart of 6 inches=1 statute mile generally places the soundings to represent 3000 square yards per sounding.

Where outcrops of rock are found under a sand bottom it is advisable to sound the area under examination in three cross lines of soundings varying in azimuth by 120°.

This produces a triple sounding sheet from which the elevations may be picked out and placed on a fair tracing for contouring.

Alteration of Scales.—In copying or transferring detail from one plan to another liberties should not be taken with the scales.

As a general rule the scale should not be enlarged; that is to say, one should not take marine chart having a scale of 1 inch to the mile and reproduce by enlargement to 6 inches to the mile. The effect of such an increase from original scale is to produce a blurred enlargement which may be inaccurate and possibly misleading in detail.

Preparation of Sounding Sheets.—Sounding sheets should be prepared on stout drawing cartridge paper mounted preferably on canvas or on a board to which the plan has been

pasted and allowed to dry. Bristol board is useful for small plans. The features of the dredged area can be drawn in after the points have been transferred by tracing paper or by measurement from the triangulation or Ordnance sheet.

Working sheets prepared on those lines are practically weather-proof. Wetting or damping of sheets either in printing process or from weather affects the accuracy of the plan.

The Marine Surveyor's Methods.—To describe the methods employed for a coastal or open estuary survey means an explanation of marine surveying in general, viz.:—

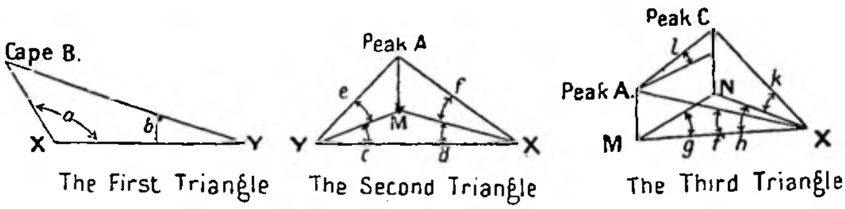
Marine or hydrographic surveying consists chiefly of the investigation and graphic illustration of waters contiguous to coastal areas, those surrounding outlying islands, estuaries, and overlying deep sea banks. There are other branches such as the examination of inner harbours and tidal rivers—the conservancy of rivers in particular.

On the Field.

Entering a bay which offers an anchorage from the prevailing winds, the surveyor, either by a pre-arranged plan or

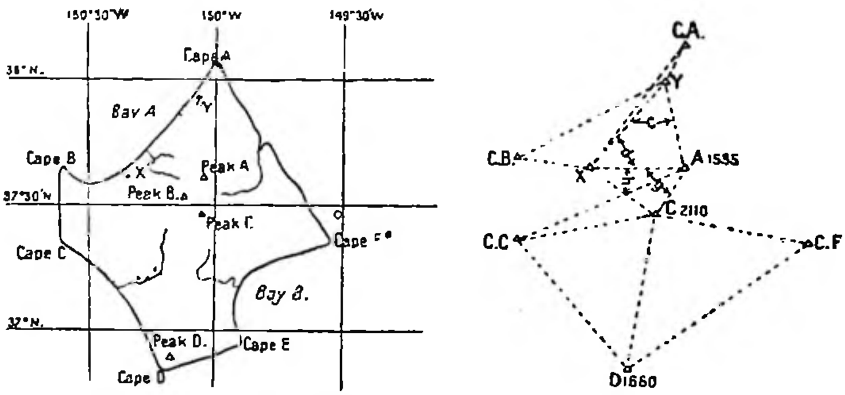
in seizing an opportunity which has presented itself carefully estimates the extent of his field in order to decide on the scale of the survey sheet.

To map a large area requires a scale which must be comprehensive 2 or 4 inches to the sea mile, otherwise the sheet



Plan of Triangulation.

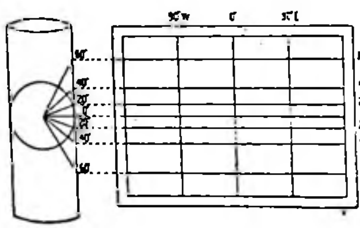
would be unwieldly. To map a small area—a large scale—6 to 12 inches to the sea mile may be used. It is considered desirable by hydrographers to survey on a slightly larger scale than that of the published chart—the process of reduction in scale tending to nullify any small irregularity of pen and paper.



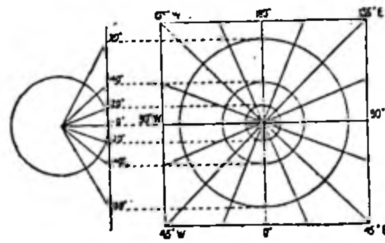
Obtaining the Value of Sides by Angles and Formula.

Small scales therefore are adopted in representing general areas, while large scales supplement these in plans of harbours, river entrances and anchorages. There are other important reasons for mapping harbours on a large scale, and consequently contenting ourselves with the more limited horizon it offers.

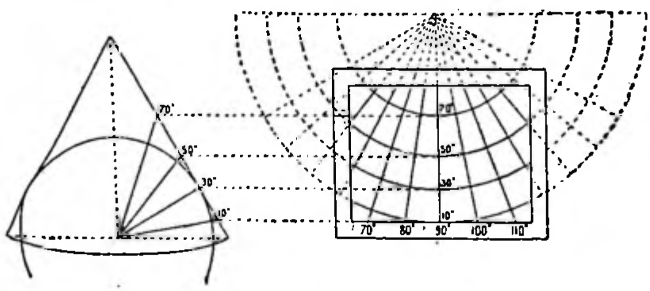
Bearings may be laid down, and the movement of a ship plotted with greater accuracy when the scale is large. In fact, the nearer we approach with our scale to the natural size of the field itself the closer we may navigate by the chart. Unfrequented parts of the world usually receive a small scale survey, covering a long stretch of coastline with the positions of the more important points fixed by astronomical observations.



Cylindrical Projection.



Gnomonic Projection.



Simple Conical Projection.

The Projection for Maps.

Later, as trade may increase the value of a particular part of the coast, it becomes necessary to survey the newly developed portion on a larger scale. Guided by the foregoing consideration, we have the surveyor landing to measure his base from which to construct his primary triangles. Having done so, he proceeds to cover the whole field with a system of distances connecting and intersecting the stations and points trigonometrically. This is his triangulation, and the distances are usually calculated in feet to third place of decimals by the rule of sines.

He now possesses a rigorously correct network of measurements enabling him to plot his stations on a plane sheet.

Portions of the work are then transferred to sectional sheets or boards, which enable a start to be made with the soundings. These are obtained in steam or pulling boats by running systematic lines from shore to shore, generally at right angles to the trend of the coastline, and soundings at intervals which depend on the depth of water. During soundings, tidal observations are noted by a watcher, or by an automatic recording tide gauge, for the purpose of reducing the soundings recorded at varying times of the rise and fall to a common level, usually L.W.O.S.T.

The soundings are then collected on a fair tracing of the whole. Coastline and topography next receive attention and are transferred from the field boards to the collecting sheet, and a fair drawing on canvas backed cartridge paper of the combined features surveyed.

Next the line of the true meridian requires attention, hitherto not necessary to the progress of the survey in other than approximate degree.

Now, however, it must be observed with accuracy by theodolite, in order that a line passing through two main stations at the extremities of the triangulation if possible may be given a rigorous value in azimuth. This is termed "obtaining the true bearing."

If the survey is intended for reproduction as a navigating chart we have then to transform the work thus plotted on the assumption that the area under survey is a plane, to a spheroidal representation.

The earth being an oblate spheroid, any part thereof is relatively rotund. The surveyor therefore, before handing over his work to a draughtsman, calculates the spheroidal corrections, usually replotting on the gnomonic projection from which it is possible to develop the chart to the Mercator's principle, as used by the mariner.

The final stages include calculation for the converging

of the meridians forming the east and west limits of the chart. A datum mark for tidal reference is then cut on a waterside rock or stone to indicate the actual measurement between L.W.O.S.T. and *terra firma.*

Astronomical observations may be taken to fix the geographical position, by a sextant fixed to a tripod stand, using a mercury bath of an approved pattern as an artificial horizon.

There are other methods of obtaining the precise geographical position of a main station, such as a fort or citadel, lighthouse or certified telegraph station.

If such a position is registered in the land surveys of the district or in other documents of reliability, the geographical position can be accepted, but if it is incorporated in a triangulation the position should be known with precision, say, within $\frac{1}{4}'$ of a geographical mile at least in latitude and closer than $\frac{1}{4}'$ of longitude.

Tide Gauges—Automatic Records.—It is generally regarded as an indispensable unit to have an automatic tide gauge installed in modern harbours. These gauges maintain a continuous record of the graphic type and run for a considerable period without overhaul, provided that the lubrication is attended to. It is customary to change the tide charts fortnightly as the scale of the height and time divisions places a limit on the dimensions of drum and chart.

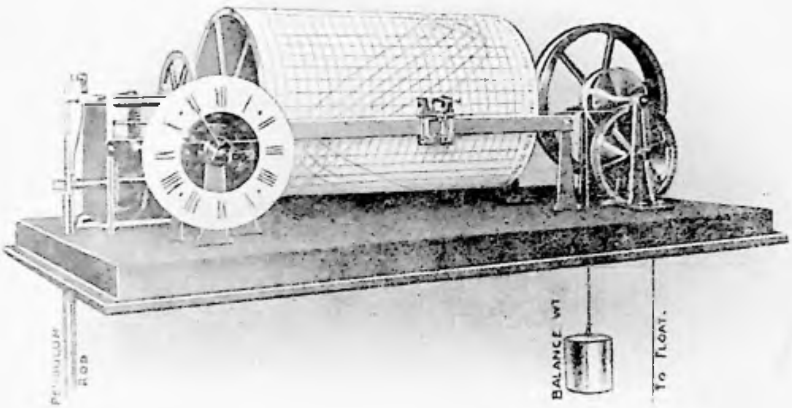
When it is necessary to have a continuous reference of the rise and fall during dredging operations these automatic tide gauges are invaluable. The disadvantage, if any, is the reduced scale which is usually 12 times less than that of the natural movement.

In Britain the automatic tide gauges installed at Dunbar, Felixstowe and Newlyn in connection with the re-levelling of Scotland, England and Wales are probably the best in the country.

The gauge consists of a revolving drum 25 inches long by 8 inches in diameter mounted horizontally with its spindle working in ball bearings, and driven by a high class 8-day clock movement rotating the drums once in 24 hours.

On the revolving drum is fitted the tidal charts on a scale of 1 inch = 1 foot, and over the length of this drum is a tramway bar upon which runs the carriage holding an ink pen or lead pencil. This carriage is moved to and fro along its bar by means of a pierced copper band, to which it is clamped, working over a small sprocket wheel fitted on one of the spindles of the geared wheels attached to a 12-inch sprocket wheel, over which the main copper band works and is attached to the float.

The float is exceptionally large—18 inches in diameter and is of copper—and the spare end of the float board after



Palatine Type of Automatic Tide Gauge Recorder.

passing over the large sprocket wheel is connected to a gathering wheel, to the spindle of which is attached a fusee, wire cord and lead weight; by this means the weight of the float and its copper band is counter-balanced.

The working parts are of brass, mounted on an enamelled iron base with standards. The charts require to be of special manufacture and are usually drawn on stone.

The Palatine Horizontal Tide Gauge has a cylinder of 9 inches. (*See* illustration.) It carries a chart on which can be obtained a record of 28 tides. The cylinder is revolved

every 24 hours by clockwork mechanism giving a record of half an inch to the foot. The pencil or pen arrangement is that of the Ditman pen, which is operated by a large float. The time divisions are $1\frac{3}{16}$ inches wide. The clock is of the dead-beat escapement type capable of going 14 days without winding.

Lege & Co. have produced some fine automatic gauges providing a type having a reversal of the principles of the Cary Porter gauge, in that the float operates the drum in place of the clock, the time mechanism operating the pencil carriage.

Illuminated Tide Gauges.—Illuminated tide gauges are sometimes of use for dredging. The difficulty of illumination lies in the unsatisfactory results of flood lighting which becomes opaque in hazy weather. The better method is to have the figures illuminated from within the structure. With the internal illumination method the figures can be seen from a considerable distance. The cost of such an arrangement is comparatively high and would appear—for dredging purposes—to be only justified when a graduated tide table for rise and fall, which can be calculated, is not sufficient for the conditions.

We shew pictorially one such tide gauge with large figure indicator, illuminated internally by oil lamp or electric lamp, capable of a visibility in clear weather exceeding one mile at night and a similar distance by day, using binoculars to assist in the reading.

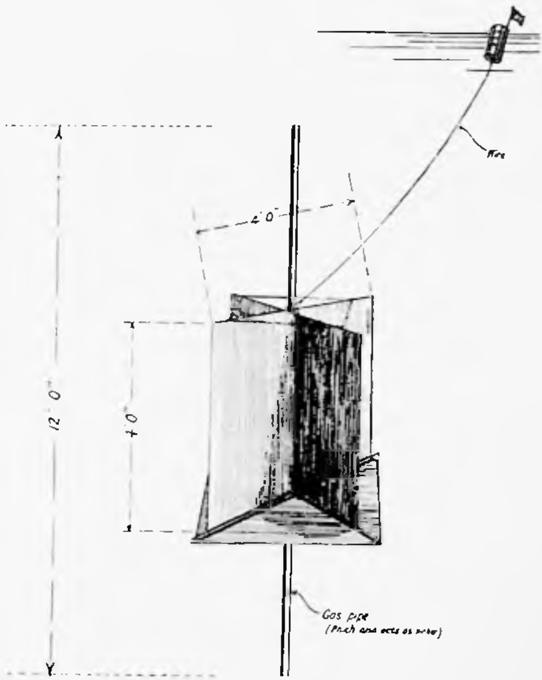
Determination of Currents in Rivers and Tidal Streams for the Purposes of Dredging, etc.—There are three principal characteristics in the energy of rivers or tidal streams. The direction, the duration, and velocities. Whether the information is local or general, the same methods of current determination may be applied to ascertain the values referred to.

When tidal rivers are dredged to admit of a greater tidal wave, scouring and silting undergo certain changes, and current determination is sometimes an essential part of a dredging-cum-improvement scheme.

Current observations may be taken by submerged floats of the box kite type or rod floats, either of which are immersed

at the required depth depending on whether the surface—mean —or bottom velocities—directions—and durations are required.

If the float is submerged deeply so that it is no longer visible on the surface then an indicator float should be attached for surface observation. This surface float should never be more than 10 per cent. in area of the submerged kite or rod, because the surface velocity being usually greater might cause towage of the submarine float by the surface indicator.



Box Kite Float.

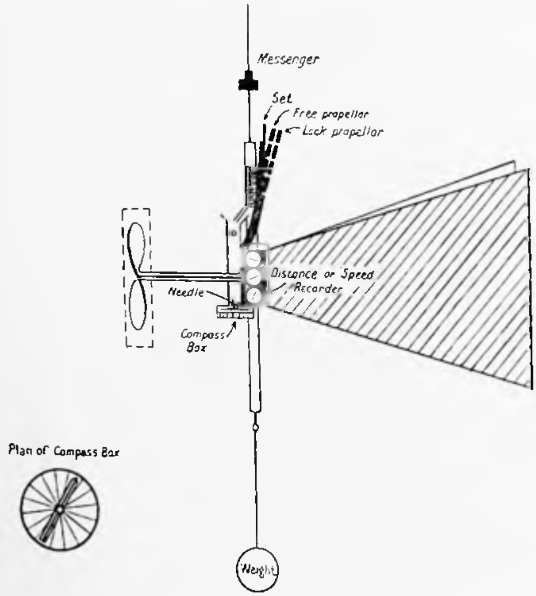
These floats must be followed by the surveyor in a launch or boat and the positions fixed by sextant angles at stated intervals. They may run aground or into shallow water in which the line should be shortened and if necessary the flotation level readjusted.

If the floats possess buoyancy, weight may be added to

sink the float to any required depth. Our illustration shews a typical box kite float used in the Thames tideway.

Of the stationary type we know the Ekman Meter best; our diagram shews the outline of mechanism. The meter is suspended by a wire and maintained in the vertical position by a weight.

The propeller and direction fins are in the same plane.



Ekman Current Meter for registering Force and Direction.

There is a lever for locking or unlocking the propeller. At measured intervals, at discretion of the operator, a messenger weight is sent down the cable of which suspends the meter to ship or boat. This messenger releases pellets which then fall into a compass receptacle, indicating thereby the direction of the prevailing current according to minutes of pellets in the quadrants. It is necessary to use a factor to convert the velocity recorded to normal terms.

If the survey of the currents is of a more extended nature

such as may be necessary for river gauging to ascertain volume, discharge, etc., then the implements and all that they may be capable of require a lengthy explanation.

We have therefore reserved for those requiring a fuller knowledge of the implements and their functions a detailed explanation which comes under "River Gauging" and follows herewith.

Notes on River Gauging.

Discharge of Rivers.—In order to arrive at the volume of a river or stream, it is necessary to know two things: (1) The cross sectional area of the river at the time of gauging. (2) The average or *mean* velocity of the river at the time of cross section. In other words, the discharge is a product of two factors, the mean velocity and cross section; and the cross section again is a product of two factors (width and depth). If these two factors are known, the cross sectional area, multiplied by the mean velocity, gives the discharge. It may be observed that where the cross section of a river is divided up into sections, and the velocities are taken in each section, the mean of the sum of these various velocities will rarely give the same result as dividing the discharge by the entire cross sectional area.

Cross Section.—Forty per cent. of the river flow, for example, may flow in 15 per cent. of the cross section.

The object of dividing up the cross section is to determine the distribution of the flow of the river throughout its cross section.

The cross section of a river is fairly easily obtained on a calm day; it is the *second* factor—the mean velocity—which presents the difficulty.

It is a matter of common observation with rivers and streams of all sizes that, although in a straight reach free from obstructions, the main body of water may have a down stream motion, its velocity varies in different parts of the channel, being usually at a maximum in the centre of the river, and gradually diminishing towards either bank.

Velocity and Impulses.—Further, although this is not often apparent by inspection, the *vertical* velocities vary from the surface of the water to the bed of the river. If the flow of water, however, be examined more closely, it will be found that the general downstream flow appears to be subject to variations as regards velocity; that is to say, that the velocity at any particular point in a given section of the river is almost constantly changing, rarely continuing steady for more than a short time, after which it either increases or diminishes, changes of a similar nature occurring at other points in the cross section of the river.

There is thus a succession of *waves* and *impulses*, which cause the velocities at certain points in the cross section to vary from time to time—sometimes considerably—the mean velocity for the entire cross section remaining the same.

Numerous experiments have shown that the flow of both small and large rivers is affected in this way, the lesser waves or pulsations lasting from about 30 to 60 seconds, whilst the duration of the larger waves is from 5 to 10 minutes or more.

The pulsations are usually found to be greatest at the bottom of the river, decreasing towards the surface. These periodic waves may frequently be noticed by observing the long strands of weed which grow in many rivers, and noting the angle at which they lie to the axis of the river. For possibly the space of a few seconds, or even minutes, a particular tress will be seen to lie parallel with the river's axis; then for no apparent reason the strand of weed will move across to angle, perhaps, of 30 degrees with the axis of the river, remaining there for a certain period, and afterwards returning to its original position.

Observations have shown that these pulsations are extremely limited in their extent at right angles to the current, but that they can be followed for some considerable distance in the direction of the axis of the current. This has been shown to be the case by recording the pulsations by the current

meter, and plotting them upon squared paper, using time as abscissae and ordinates as velocity.

It has been found that these impulses affect the whole depth of the river, their effect decreasing, as has already been said, from the bottom to the surface of the river.

Harlacher found the velocity near the surface of the river to vary 20 per cent. in a few seconds, whilst near the bottom he found it to vary 50 per cent. in the same period of time. The impulses occur quite apart from any alteration in surface level of the water, and the law or laws which they follow have not, so far, been discovered.

The variable and complex flow of water in a river has not inaptly been compared to a cloud of smoke on a windy day.

It is important to refer to these pulsations at some length, as they may affect gaugings of river by "direct" methods to a marked degree.

Discharge measurements of rivers may conveniently be divided into two classes—

(1) Direct measurements.

(2) Indirect measurements.

By direct measurements is meant the direct measurement of the velocity of the water by bodies floating in it, such as surface and rod floats, double floats, etc. Indirect measurements comprise records obtained by current meters, pressure plates, moving diaphragm, etc. That is to say, the velocity is inferred from recorded impact, pressure, etc.

Float Methods.—It will be desirable to dwell for a moment upon float (direct) methods of obtaining velocity, and to contrast them with current meter methods, also to give a few of the advantages and disadvantages inherent in each method.

Floats may be roughly divided into three classes, comprising—

(1) Surface floats.

(2) Double or compound floats.

(3) Float rods.

N.B.—Floats shew both mean direction and mean velocity, and may also by careful weight, $\frac{\text{in atmosphere}}{\text{in water}}$ give suspension factor of stream.

In float work, a straight stretch of river is selected, and the average cross section is ascertained over a length of, say, 50 to 300 feet; the longer float run—other things being equal—the better. This usually involves a number of cross sections. Floats are put in at the head of the runs or "swim" and the time they take to travel the measured distance is noted. Then $\frac{\text{distance}}{\text{time}}$=surface velocity at that point for that particular time, assuming surface floats to have been used. Concerning float work generally, it should be noted that when floats are used the velocity is only obtained for a short time of a comparatively few particles of water, and the mean velocity must be found from the relation between surface velocity and mean velocity, relations which are by no means so well established as could be desired. Floats are carried along by a single pulsation of water, and are not affected by succeeding pulsations. It will be recognised from this that, where only a few observations are made by float methods, these may chance to be taken either during a period of maximum impulse or of minimum impulse in their particular swim, and the velocity recorded may be too high or too low as the case may be. Unless, therefore, the float observations are sufficiently numerous—say 20 to 40 runs over a given length of the river—and the mean time taken, erroneous results may easily occur.

Surface floats consist of bodies floating on or near the surface of the water; lightly weighted wooden discs or cubes, oranges, turnips, or corked bottles weighted so as to float with just a portion of the cork showing above the water. With surface floats, the surface velocity (or approximately the maximum velocity in the case of shallow rivers) is obtained, and a coefficient must be found to get the mean velocity. Wind is specially liable to vitiate surface float work.

Double or compound floats usually consist of a light surface float connected by a wire, cord or chain to a heavier submerged body, whose depth beneath the surface is regulated by the cord or wire. Such floats are intended to give approximately the average or mean velocity of the section of the river in which they travel. Compound floats cannot be regarded as altogether satisfactory, since for one thing the connecting cord, wire or chain is very apt to twist and so shorten, even when a swivel is inserted; further, it is most difficult, particularly in a swift current, to locate accurately the exact position of the submerged float, thus travelling at less than its proper depth and giving in consequence too high a velocity. In any case, unless the river bed underlying the float runs is most singularly even, and free from weeds and other obstructions, the average velocity obtained will be in excess of the true mean velocity, since even in the most favourable conditions it is impracticable to let the lower float travel much nearer to the river bed than about 6 ins.; and it is at this depth where the velocity normally approaches a minimum. Double floats in common with surface floats register the velocity of a single impulse only, and they are likewise affected by wind, although to a lesser extent.

Float rods generally consist of wooden rods or hollow metal tubes $\frac{3}{4}$ in. to 2 ins. or so in diameter, so weighted as to leave from about 1 in. to $1\frac{1}{2}$ in. of the top of the rod above the surface level of the water. They form the best kind of float for certain purposes and they are especially useful where there is much loose floating grass or weed. Float rods do not interfere materially with the natural flow of the water: they measure forward velocity and they are not costly to make. With the ordinary type of float rod, several lengths of rod are needed for the various swims of a measured length of river, according to the several depths of the section. The writer has found light telescopic metal tubes convenient, since they can easily be adjusted to the required depth.

Float rods have their limitations. Besides only giving

the velocity of a single impulse, they are affected by wind and cannot be used in deep rivers or rivers which have rough or irregular beds. They are somewhat expensive to operate, owing to the number of observers and boats needed, and, as in the case of double floats, they usually give a somewhat higher

Under Water Kite.
Used to determine Direction, Velocity, and Duration of Under-surface Stream Lines.

velocity than the true velocity, since they cannot be extended to the full depth of the rivers which they travel. It should be noted, however, that unlike the double float, the angle of inclination of the top of the rod with the surface of the water shows the observer whether there is a sub-surface drag or push.

Floats are very rarely of the same specific gravity of the

liquid in which they travel, and they cannot therefore be expected to give the same velocity as the water they swim in. The closer the specific gravity of fine silt or similar suspended matter approaches that of the water in which it moves, the closer does its velocity approach that of the water which transports it.

Comparisons between float and current meter results are given later.

Indirect Methods.—The only devices which will be considered here are current meters. These are somewhat difficult to classify, some meters being of the screw (propeller) form, whilst others are made on the revolving cap or the vane principle. Possibly the best way to consider them will be under the following headings.

(1) Meters in which the revolving part of the instrument is attached to a horizontal axis (*e.g.* the Haskell meter).

(2) Meters with the revolving portion on a vertical axis (*e.g.* the Price meters).

In the case of meters with a vertical axis friction is generally least, since it virtually all comes on one point and this point is carefully protected against grits, knocks, etc. It has been established that for high velocities a wheel revolving on a vertical axis does not move so rapidly as one placed on a horizontal axis under the same conditions; also the wheel will begin to revolve at a lower velocity than the horizontal axis meter.

A Haskell meter, for example, requires a velocity of about 0·20 ft. per second to start the propeller, which makes about 6·5 revolutions per second in water having a velocity of 7 ft. per second; whereas a meter of the second class, such as a Price meter, needs a velocity of only about 0·06 ft. per second to start it, and it makes only 3·02 revolutions per second in water having a velocity of 7 ft. per second. Now, three revolutions per second can easily be counted, but 6·5 revs. per second cannot.

The current meter differs inherently from floats in that

it registers instantaneously *all the impulses*, striking it during the duration of the observation and it gives the *average* or *mean* velocity due to these impulses. The current meter possesses many advantages over other methods of measurement, quite apart from the fact that it gives integrated or mean velocity; it can be used upon rivers of all sizes, provided that the velocity of the water is adequate; moreover, only one cross section is needed.

Further, when the river is ice bound, the current meter can be used with the greatest of ease. On the other hand, the meter cannot often be successfully operated where there is much floating grass or weed; or in streams of sluggish flow it also requires care in handling and careful rating before use. The greatest care should be taken with current meters, both in using them and in putting them away after use, as they are easily damaged by carelessness. If there is any suspicion that a meter has received any injury, it should at once be overhauled and re-rated.

Some extremely interesting experiments were made by Mr. E. C. Murphy, at the Cornell University, for the purpose of comparing the discharge records obtained by current meters with the corresponding discharges ascertained by weir measurements.

It should be mentioned that the bed of the Cornell Canal—on which the experiments were conducted—is stated to be smooth, hard, and regular in shape, whereas the bed of a river is not infrequently of soft material into which the foot of the meter may settle; or again, it may be gravelly, stony, or irregular in shape.

Weir measurements of discharge are, of course, the most accurate methods to employ in the case of small streams, but where large rivers are concerned they would be prohibitive by reason of the cost of constructing the weir.

Careful investigators have estimated that the relative accuracy of various methods of measuring large volumes of water under favourable conditions, are about as follows:—

* Moving diaphragm ½ to 1 per cent. error.
Weirs 1 ,, ,,
Current meters about 2 ,, ,,

Mr. Murphy, in his experiments on the Cornell Canal, compared the discharges obtained with a sharp crested weir with the discharges found by current meters. The mean velocity (by the integration method) was found by dividing the number of revolutions of the meter wheel by the corresponding time, and converting the quotient into velocity. The ordinary, or point, method was also used for obtaining the mean velocity, the results obtained by the two methods agreeing closely, the greatest difference being 3 per cent. integration giving the highest velocities.

From his experiments Mr. Murphy drew the following conclusions:—

(1) Discharge measured with current meter by the ordinary (point) method agrees with that given by the Cornell standard weir within 2 per cent. for velocities above 1·5 ft. per second.

(2) For velocities less than about 1·5 feet per second. the discharge found with the Price meters is less than the corresponding weir discharge, and the difference increases rapidly as the velocity decreases.

(3) For velocities less than about 1·5 feet per second, the discharge found with the Haskell meter is greater than that of the weir, and the difference increases as the velocity increases. This difference is 6 per cent. velocity of 0·75 ft. per second.

(4) The discharge of the Cornell Canal can be measured by a small Price meter, ordinary point method, with an error of not more than 1 per cent. under favourable conditions, a velocity observation lasting 50 secs. being taken in each 2·3 sq. ft. of discharge area.

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* This particular method, however, can only be employed in artificial channels of uniform cross section.

(5) When the most accurate results are desired, the meter should be held with a rod and given freedom to tip.

(6) Velocities of 1·5 ft. per second and upward obtained with a small Price meter when its centre is closer to the surface than 0·5 feet are too small by from 0 to 9 per cent. This error, however, decreases from a maximum at the surface to 0 at about 0·5 ft. depth.

(7) The small Price meter will measure velocities of 1 ft. per sec. and less more accurately than either the large Price meter or the Haskell meter. It appears from these experiments that the smallest velocity that these meters will register with a fair degree of accuracy is 0·5 ft. for the large Price meter and the Haskell meter, and 0·22 ft. for the small Price meter.

(8) The small Price meter should be frequently rated, and it should be used with much care if accurate results are required.

(9) The six-tenths depth method gives discharges from 2 to 6 per cent. in excess of that by the weir, depending on the ratio of width to depth.

(10) The integration method as a rule gives results in excess of those given by the weir, the difference increasing with the speed of the water and decreasing as the velocity increases. By using special care in moving the meter at a slow speed and a uniform rate, it may be possible to obtain better results by this method than those shown by these experiments. A device like Harlacher's for giving the meter a uniform motion will increase the accuracy somewhat. We do not believe, however, that the little saving of time of this method over that of the mid-depth, or the six-tenth depth, will warrant the use of any such device. The method is useful only as a rough check on one of the other methods.

(11) The thread of maximum velocity is at the surface for depths less than 2 feet and unobstructed flow at the lower end of the canal. For depths of 5 feet or more and discharge checked at the lower end of the canal; this thread is from two-tenths to four-tenths depth below the surface, the mean of 31 experiments being 30-hundredths depth.

(12) *Mean Velocity of Rivers.*—The position of the thread of mean velocity varies from five-tenths depth for small depths to 73-hundredths depth for the larger depths. For the 31 experiments by the ordinary method of series C and D it is 64-hundredths depth below the surface.

(13) The surface velocity is always greater than the bottom velocity, with centre of meter 0·25 ft. above bottom.

(14) The ratio of bottom velocity to mean velocity varies from 0·6 to 0·9, being 0·8 for the experiments of series A, 0·75 for series C, and 0·85 for series D.

(15) The ratio of mean velocity to mid-depth velocity varies from 0·90 to 0·99, the mean of 40 experiments being 0·95.

(16) The average of the velocities 0·5 ft. above the bottom and 0·5 ft. below the surface is from —2·2 per cent. to +20 per cent. less than the mean velocity shown by the weir.

(17) A small Price meter will revolve faster in moving water of a given velocity when held with a rigid rod than when held with a cable. Hence the same rating table will not answer for both.

(18) The bottom velocity varies between so wide limits that it is not a desirable quantity to use in computing discharge; the mid-depth or six-tenths depth is better.

From the foregoing conclusions it will be seen that it is inadvisable to use current meters for measuring very low velocities, and in such cases floats should be employed.

It may be observed that Messrs. Fteley and Stearns, at the Sunbury conduit, checked the Fteley meter vane pattern, against two weirs, and found the respective discharges to be in close agreement for depths of water of from 1 foot to 4 ft. 6 ins., there being usually only a fraction of 1 per cent. difference.

As regards float measurements of velocity, the results of D. F. Henry showed the current meter to give a little lower velocity than floats.

Gordon's experiments on the Irrawaddy River, Burma, showed the discharge as obtained by double floats to be 10 per cent. in excess of the meter discharge; and other experimenters obtained figures 6 to 26 per cent. in excess. In another case the float velocity was 3·5 per cent. in excess of the meter reading.

Float rod experiments—with 80 to 90 per cent. of the rod immersed—when compared with meter results carried out at Lockport and Boonville agreed better; the time of run of individual rods, however, differed largely.

Concerning comparisons between discharges arrived at by float rods and weirs, it was found that the discharge obtained by float rods were within* 2 per cent. of the discharge given by the weir. The mean error for all depths and velocities was 3·54 per cent. for 75 per cent. immersion. The standard weir discharge was found to be too small by from 0·5 to 2·5 per cent.

Rating Current Meters.—Before the current meter is used, it must be rated; that is to say, the relation between the revolutions of the meter wheel per second and the velocity must be established, and upon the care with which the rating is performed will depend very largely the accuracy of discharge gaugings, especially those made in moderate to low velocities.

There are several ways of rating current meters, such as moving the meter through still water with a known velocity; fastening the meter to a long arm and revolving it in still water about a vertical axis; or again by moving the meter

* It would naturally be expected that the discharge ascertained by the float rods would be the greater since rods cannot ordinarily be extended to the full depth of the channel.

through running water and back on the same course, in order to neutralise the effect of velocity in one direction, a method which has the advantage of carrying away any currents set up by the meter.

The rating should be carried out with due regard for the velocities which will actually be encountered in practice, *i.e.* the range of velocities used during the rating should be those for which the meter is likely to be used; *i.e.*—

If it is to be employed mainly for low velocities, the speeds adopted in rating should be low; further, if a cable suspension is going to be used for the meter, the rating should be carried out with a cable suspension. This precaution is a necessary one, since the rating table of a small Price meter when held with a rigid rod differs somewhat from the table applicable to the same meter when suspended by a cable and free to tip.

Hence, when used with a rod, the proper rating table should be employed. The small Price meter wheel is found to revolve somewhat faster when held by a rigid rod than when held by a cable.

If current meters are to be used in turbulent water, *e.g.* tail races, special ratings are necessary, since it has been found that under such conditions screw (propeller) meters under-register; whilst, on the other hand, cup meters over-register when the velocities are based upon still water ratings. Hence, unless the meters are specially rated, they will give erroneous results under such conditions. If it can be arranged, boiling, eddying water should be avoided; when this is impracticable the vane of the current meter should be removed.

The rating table (referred to later) should not be extended beyond the limit of the velocities used in the rating. The usual procedure adopted in rating a meter in *still* water is as follows:—

The meter is suspended from a car or boat, and moved with uniform velocity through still water of a depth of not less than about 5 feet, and free from weeds.

The meter should be held not less than about 2 feet beneath

the surface of the water, to avoid the effects of possible surface currents. The day selected for rating purposes should be calm and the surface of the water free from ripples.

The length of run used may vary from 100 to 300 ft. according to circumstances, with a starting run sufficient to permit of the meter wheel reaching its proper speed before entering the run.

If a boat is used it should be towed by a line passing over a pulley at the head of the run, and the boat used should have a sharp stem.

With the car method, such as is used at a regular rating station, the meter is suspended from a small car and trolley, which runs on rails alongside of the rating pool. If neither of these methods can be used, the meter can be carried along through the water by hand, provided there is a level path or coping bounding the rating pool or reservoir. The meter should be propelled through the water 20 or more times in succession, at varying speeds, the number of revolutions of the meter wheel carefully recorded. When rating in still water, it is best to wait 10 minutes or so after each run to allow the water to become quiescent again.

The timing appliances for special rating stations usually record the times of the runs to one-tenth of a sec. and the speed of the meter wheel to tenths of a revolution. A chronograph recording time, revolutions, and moments of starting and ending the run is often employed for this purpose.

The results of ratings may be conveniently plotted on squared paper, using revolutions as ordinates and velocities as abscissae, all doubtful observations being excluded.

The most probable curve is then drawn amongst the plotted observations, and the velocities to a tenth of a revolution are read from the curve. From this curve are taken the values to form the arbitrary relation between revolutions of meter wheel per second and the speed of the water. The reduction table thus formed usually reads to three places of decimals.

The relation between the distance travelled by the meter

and the corresponding revolutions is not represented by a perfectly straight line. Friction of bearings and the inertia of the revolving wheel cause it to be more or less curved. Higher velocities show as practically straight lines, but the lower velocities owing to the action of inertia and friction appear as a somewhat curved line.

It should be observed that when a cable suspension and a torpedo weight are used the weight has the effect of reducing somewhat the discharge area near the meter, consequently increasing the velocity and affecting the number of revolutions of the meter wheel. The torpedo weight, when attached to the hanger at a distance of 6 ins. from the meter, will cause the wheel to revolve perceptibly faster than if attached at 12 ins. distance. Hence, a rod should be used when extreme accuracy is needed. The ratings of meters should be examined weekly when the instruments are in frequent use, if the greatest accuracy is desired, *i.e.* considerably oftener than levels are, or should be, tested for adjustment when in use.

It is found that the number of revolutions of the wheel of the small Price meter traversing a run of 100 feet varies from 42 to 44; *i.e.* practically the same number of revs. are made, regardless of the speed, in the same way that the wheel of a bicycle revolves a given number of times in travelling a certain distance, irrespective of the speed at which it travels.

Standard rating tables are sent out with each instrument by the makers of the small Price meter, and it has been found that these tables give results within about 1 per cent. of individual rating tables specially prepared—provided, of course, that the meter is in good order.

It should be noted that for low velocities it is specially important that the bearing point of the wheel axis should be sharp. For high velocities this is of less import, as friction then becomes almost negligible.

In obtaining the discharge of a river it is necessary to obtain as accurately as possible the mean velocity of the river at the point of gauging.

This can be most accurately effected by what are known as vertical velocity curves, at a sufficient number of points across the river; the method, however, takes a long time to accomplish and there is considerable risk of the stage of the river altering meanwhile. If a change of stage should occur, the cross section is altered, and usually the velocity also, the discharge of the river in consequence either increasing or decreasing, and it is therefore necessary to devise methods of obtaining the mean velocity, which whilst giving sufficiently accurate results for the purpose in view can be carried out fairly expeditiously. There are several such methods, each one being suited to certain conditions, and they will be referred to later.

Vertical velocity curves taken in the different parts of the discharge section are not infrequently amalgamated by combining the velocities at each tenth of depth, but this plan assumes that the curves are similar in all parts of the discharge section, and this is seldom found to be the case in practice.

Once the relation between depth and velocity in a vertical section of the stream, parallel to the thread of the current, is established, the velocity ratio at any depth to mean velocity can quickly be found, and the discharge for that particular river stage calculated from meter readings taken at one depth only in the vertical.

As regards the changes which occur in the vertical velocity curve with alterations in river stage, data are somewhat meagre; with a rising bed the effect of roughness of bed decreases, whilst that of hydraulic radius and surface slope increases with additional river stage.

Further detailed research appears to be needed regarding the question of the relations between velocity and depth, and the changes which this undergoes with changes of river stage.

The form of vertical velocity curve varies considerably according to local conditions, *e.g.* velocity, nature of bed, obstructions, wind, surface slope, ratio of depth to width, etc.

Generally speaking the curves are parabolic in character.

It is found in practice that a rough river bed, largely owing to eddies formed at the bottom of the river, has the effect of causing a drag, or retardation, at the lower portion of the vertical velocity curve, which tends to elevate the line of mean velocity in the cross section.

In such case an 0·6 depth measurement would be less than the proper value; and conversely a smooth river channel 0·6 depth too large.

Vertical velocity curves may be obtained in two ways:—(1) By a single meter plan; (2) by the multiple meter plan.

In the first method—which is the least costly, and is usually adopted—the meter is held at as many points in a vertical as desired usually at each tenth of the depth, being held there for a period long enough to eliminate pulsations. In a deep river this may require one or more hours to a vertical, during which time the stage of the river may have altered and consequently the mean velocity also. In cases such as these the difficulty is sometimes surmounted by employing several meters at once, or even sufficient meters to give the whole vertical velocity curve in one setting.

When this is done the meters are spaced at each tenth of the depth of the vertical on a cable or rod—preferably the latter—provided with a heavy bottom weight. Each meter is connected to an electric register, and all the circuits are opened together by a switch.

A stop watch is started at the moment the circuits are closed through the meters and recorders. When the meters have run for the allotted time the circuits are opened simultaneously with the stopping of the watch.

With a number of meters the time for observation for one vertical can be extended to 10 minutes or over.

After the velocities have been booked, they are plotted upon squared paper, using the depths of the centre of the meter below the surface as ordinates, and the velocities as abscissae. A curve is then drawn through the points thus obtained. The mean abscissa gives the mean velocity of the curve.

The ordinate cutting the abscissa at the point of mean velocity shows the depth below the surface of mean velocity.

Another method of finding mean velocity is to divide up the depth of the curve into, say, ten equal parts; the velocity at the centre of each part is then taken, and the mean of these several velocities gives the mean velocities for the whole curve.

The value of the mean velocity is usually determined by dividing by the depth the area enclosed between the curve and the axis. To arrive at the coefficient for reducing a current meter reading to mean velocity, the mean velocity as obtained from the curve is divided by the velocities at various depths in the vertical.

For depths not exceeding 12 ins., the vertical velocity curve is almost a straight line, maximum velocity being found at the surface, and the mean velocity about mid-depth.

For depths of 8 feet or so, where the velocity is low the curve is extremely flat, the maximum velocity being at from two-tenths to three-tenths depth, and the mean velocity at 65-hundredths to seven-tenths depth (beneath the surface.)

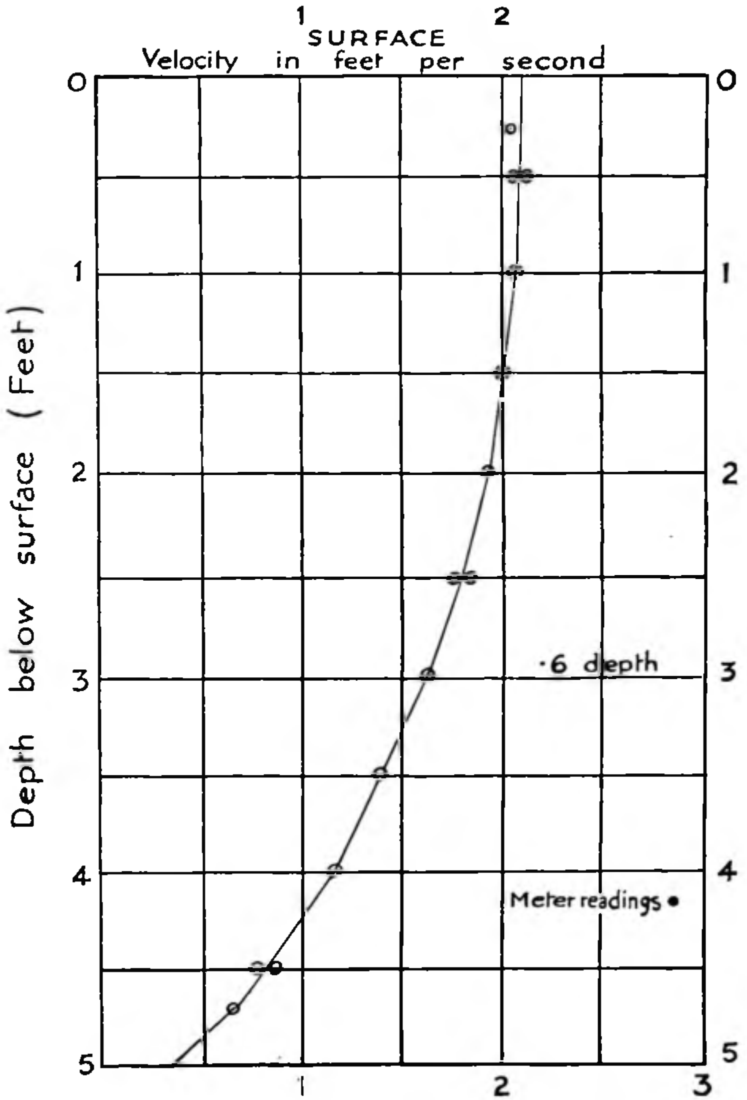
Radius of curvature increases with the velocity. In all vertical velocity curves the lowest velocity is found near the bottom.

The illustration on page 59 shows a vertical velocity curve taken on the River Ouse, near Huntingdon.

Plane of Mean Velocity.—A very large number of experiments which have been carried out in America under the auspices of the U.S. Geological Survey have shown that the thread of maximum velocity in a given vertical section occurs at a depth varying from six-tenths to two-thirds the total depth of the section measured from the surface downwards.

The ratio of depth to width is a factor likely to affect the position of mean velocity. With wide and shallow rivers, where the bed slopes gradually to the banks, maximum velocity is usually found at, or very near, the surface of the centre of the stream. As roughness of the channel increases, the thread of maximum velocity becomes more depressed; it is also found

to increase with steepness of banks, and also as the ratio of depth to width increases. In the case of deep narrow channels,



e.g. flumes, or canals, with practically vertical sides, maximum velocity occurs considerably below the surface, sometimes as

much as one-third to two-fifths of the total depth, as was found to be the case with the Cornell University Canal.

The depth of a river has a marked effect on the position of the point of mean velocity, and in the case of a shallow river it approaches 0·55 depth, or in a deeper one, 0·65 depth; in general, however, the error involved in employing the 0·6 depth is not large.

Retardation of surface velocity has been attributed to the rising of the lowermost water to the surface by vertical motion, after it has been checked in its flow by striking against the rough bottom and sides of the channel.

Strong winds blowing up stream exercise a considerable influence both upon the surface velocity, and also upon the positions of the maximum and mean velocities in the vertical.

The maximum velocity of a river in a straight reach is usually found in the central portion of the river and slightly below the surface, the precise position depending amongst other factors upon the size, condition and velocity of river. Maximum velocity usually diminishes from the surface downwards for, roughly speaking, one-tenth of the total depth; it then decreases still further until a point close to the bottom of the river is reached, where it approaches a minimum.

In experiments carried out by observers on the Mississippi River, the position of maximum velocity averaged nearly one-third of the whole depth below the surface, varying with the direction of the wind. Prof. Von Wagner found that the point of maximum velocity varied from a little below the surface to a little over one-quarter of the full depth.

Experiments carried out on the Sacramento River—the channel being composed of boulders and the water 3 ft. to 5 ft. deep at low water—showed the mean velocity to be:—

Group	Per cent. of surface velocity	Group	Per cent of surface velocity
1	87	4	89
2	88	5	87
3	88	6	87

The measurements of velocity for the above investigations were taken at the top, middle and bottom of each section, at intervals of 20 feet.

A determination made on the Twolumne River also gave a coefficient of 88 per cent. This river has a pebbly or stony bed, the depths ranging from 1·12 to 1·84 feet, with velocities of from 3 to 5 feet per sec.

Prony carried out some experiments in wooden troughs to determine the ratio between the surface and the mean velocity, arriving at a coefficient of ·816. Messrs. Baldwin, Whistler and Slosson, using channels lined with planks, obtained coefficients of ·810 to ·847.

Subsequent experiments carried out in America go to indicate that the coefficient generally lies between 0·8 and 0·9, depending largely upon the size of the channel and the nature of the bed.

The mean of 78 vertical velocity curves taken on rivers in the Southern portion of New York State showed the mean velocity to be 0·87 of the surface velocity in the vertical section. This coefficient varied from ·82 in the case of the Catskill Creek to ·93 on the Fishgill Creek.

In certain cases—*e.g.*, when the river is ice bound, and where there is slack water near the banks and return currents are caused—there may be two lines of mean velocity. This will be shown later in the section dealing with the flow of rivers under ice.

Broadly speaking, there are two ways of using the current meter for obtaining the mean velocity of a river, viz., (1) the point method; (2) the integration method.

It is not possible, within reasonable limits of space, to lay down precise rules which will apply to every case met with in practice and give uniformly satisfactory results.

Most conditions, however, can be suitably met by one or another of several operations, each method being applicable to certain conditions. The particular method adopted must be left to the judgment of the observer and it must be carefully

noted that the accuracy of the results will depend very largely upon the handling of the instrument. Some of these methods may now be described.

The chief and most reliable methods in use are the vertical velocity curve; the 0·6 depth (single point method); the 0·2, 0·6, and 0·8 depth (three point method); the integration plan; and the surface flood method.

In the ordinary or point methods, the meter is held at certain points in the cross section of the river for a given time—frequently 50 seconds—or for a given number of revolutions, these being carefully recorded.

The meter may be held at one point in each successive vertical, or at several points in particular verticals.

For example, it may be held at surface, mid-depth, or bottom velocities in certain verticals or again at (*a*) three-tenths depth; (*b*) six-tenths of depth; or (*c*) at mid-depth in certain verticals, and the mean velocity by applying a coefficient.

The vertical curve method is the most accurate way of obtaining mean velocity, but, as has already been pointed out, it also requires the most time. When time permits from three to eight observations are taken in each vertical, each observation requiring from 50 to 100 seconds, but the time required by this method can be greatly reduced if two or more meters are used simultaneously.

Owing to the loss of time involved, there is danger of change in the river stage before the observations are completed, and for that reason this method is sometimes limited to two or three characteristic verticals in the cross section, as a check upon the results obtained by other methods. For example, where the meter has been held at 0·6 depth, a few vertical curves may show that a coefficient should be applied to the readings to reduce them to mean velocity.

It should be stated that one vertical velocity curve is seldom applicable to the whole cross section, and therefore several should be taken.

The three-tenths depth is sometimes employed because it is considered to be the point of maximum velocity in the vertical, and a small error in the position of this point will not affect the result much.

The mid-depth is occasionally used because the factor which is employed to arrive at the mean velocity is more nearly constant for it than for any other point in a vertical curve. Single point methods give satisfactory results where the conditions are good, but judgment is needed as to the depth at which the meter should be held beneath the surface, the depth of the thread of mean velocity varying from 0·55 to 0·65 of the depth.

The 0·6 depth is used because, when the conditions are good the coefficient is 0 and the depth is believed to represent in most cases the thread of mean velocity. It should be pointed out, however, that whilst observations taken at 0·6 depths give fair values for mean velocity in wide rivers (and moderately shallow), this ratio should be increased to 0·67 depth in the case of canals, deep natural channels, etc.

Sometimes what are known as top and bottom measurement are taken; that is to say, the centre of the meter is held just under the surface—usually 0·5 feet$\frac{1}{4}$ under—and as close to the bottom of the river as possible, one-half the sum of these two velocities being taken as the mean.

This procedure is not always satisfactory, as the meter wheel is liable to catch up in growths at the bottom of the river, and the plan should not be used when the bed is uneven, or unless the stream is shallow as compared with its width. Frequently such rivers have a turbulent flow.

In the majority of cases, mean velocity as obtained by this plan would be too small, and the method of holding the meter at 0·2 and 0·8 depth is better, the mean of the two velocities giving practically the mean velocity in the vertical, without the use of a coefficient.

When velocities are taken at top, bottom, and mid-depth,

the mean velocity is taken as one quarter of the sum of the top and bottom velocities, plus twice the mid-depth velocity.

$$(V=\tfrac{1}{4}\ (T+B+2M)).$$

A better and more accurate plan is to take the readings at 0·2, 0·6, and 0·8 depth, the calculation for mean velocity being made as just shown.

This method, it will be noticed, is in fact an abbreviated form of vertical velocity curve.

With the mid-depth method, the meter is held at mid-depth in the vertical and about 95 per cent. of the velocity obtained is taken as the mean velocity. This method is unsatisfactory, and is infrequently used since the velocity at mid-depth does not bear a constant relation to the mean velocity.

In times of flood, surface measurements with the meter held 1 foot beneath the surface of the water are often the only ones which can be taken, since at lower depths beneath the surface—sometimes even with stay lines—the meter would be deflected upwards by very swift currents. Further, at such times, change of river stage is usually rapid, and a discharge measurement should therefore be made in the shortest time possible.

As a general rule a discharge measurement should not be passed until it has been subjected to some check as errors are sometimes traceable to faulty gauge readings, holding the meter in a hole, wrong soundings, etc., and they are far better dealt with whilst the facts of the case are fresh in the memory.

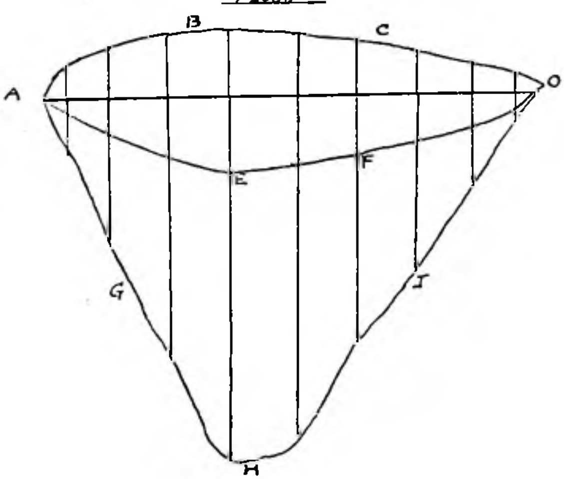
In cases where the surface velocity represents practically the maximum velocity, and the meter is held 1 ft. beneath the surface, the factor 0·85 is usually applied, to reduce it to mean velocity in the case of streams of somewhat less than moderate size and depth, but where maximum velocity occurs beneath the surface, as in the case of deep streams, 0·90 or even 1·0 should be taken as the mean velocity.

It may be noted that in very rapid currents, such as occur in heavy floods, a stay line is needed for the meter when sub-surface records are being taken, to prevent it being swept

upwards by the current. (A $\frac{1}{4}$-inch diameter steel strand wire stretched between two posts on either bank, and finished with a pulley or ring running on it to carry the meter stay line is useful.)

If the velocity is very great, *i.e.*, too great for the ordinary stay line, it is best to measure the velocity near the surface, say 1 ft. beneath, and to apply a coefficient to obtain mean velocity. Typical vertical velocity curves can be obtained with special stay lines, and the proper coefficient obtained.

Harlachers diagram for computing
FLOOD



Stay lines are also needed in deep or rapid streams during their normal flow, otherwise the meter will be carried at an angle from the horizontal, either temporarily, or for some considerable time, the meter wheel thus revolving at less than its proper depth.

Experiments carried out in America have shown that at an angle of 5 degs., with a velocity below 4 ft. per second, the meter wheel apparently revolves slightly faster than when it is horizontal; *i.e.*, at moderate speeds and at low inclination the meter may record a slightly higher velocity than is correct.

At high speeds and at a high inclination, the reverse

holds good, and the meter wheel turns more slowly than when held parallel to the current. When depressed below 25 degs., the resistance to the current approaches that offered by the tail (vane), and the meter swings about in a position nearly at right angles to the current causing the head to approach the normal or zero angle.

Harlacher's method of computing flood discharge, where the surface velocity only can be measured, is a useful one. The illustration on p. 65 shows this method. The procedure is as follows:—

Enough surface measurements are taken to find the surface velocity curve *ABCD*—which is in reality a maximum horizontal velocity curve—beneath this curve, using the line *AD* as a datum, the depths at points where the velocity was taken are plotted, and the line *AEFD* drawn. The product of the surface velocity and the depth corresponding to it is found a number of points, and the curve *AGHID* drawn. The area of the figure between the line *AD* and the curve *AGHID* multiplied by the coefficient 0·85 gives the discharge per second. The area of the figure can easily be ascertained by means of a planimeter.

Every care should be taken in flood gaugings to protect the meter against injury from drifting wood, etc.

Careful records of the gauge height at which the banks of the river overflow should be noted for future use in flood prevention work, etc.

In the integration method, the meter, instead of being held stationary at several points of the cross section, is moved slowly through it with a uniform speed, the time and revolutions being carefully recorded. The mean velocity for the whole cross section of the whole river can thus be obtained, or the mean velocity in a vertical only, as desired. For example, the meter may be moved slowly and uniformly from the surface to the bottom of the river, and up again several times in certain verticals only.

This method has been ascertained to give good results if the meter is moved *slowly*, and with uniform speed, but it may

be said that the small Price meter is not well suited for integration methods, since the upward motion through the water causes the wheel to revolve. The Haskell meter (propeller type) is unaffected in this way.

Harlacher has devised a special form of apparatus for accomplishing the up and down motion of the meter uniformly.

By the integration method, the velocities in the vertical are integrated mechanically and the mean velocities can be calculated by noting the time and number of up and down movements.

It is most important that the motion of the meter through the water should be both uniform and slow, thus reducing the error in the resultant velocities, due to the up and down motion of the meter.

It has been found in America, with the Fteley meter (horizontal axis vane meter) that when it is moved through the water at a velocity not exceeding 5 per cent. of the speed of the current no material errors are introduced. With this particular type of meter too rapid an up and down motion causes a decrease in the velocity indicated, whilst with the Price meter—or with any type of meter contrived to face in the direction of the resultant velocity—the results will be too large.

For both types of meter, errors (whether positive or negative) will be largest when integrating low velocities. It has been found that the most accurate results are obtained when the meter is held by a rod and the axis kept parallel to the axis of the stream. For deep water, it is usually held by an insulated wire, and is free to take the direction of the current at the point where it is held.

Another integration method consists in moving the meter obliquely up and down from one bank of the river to the other, thus obtaining the mean velocity of the whole cross section. This procedure involves the use of a bridge or wading rods; also the line of the up and down movements must be varied according to the depth, and in a variable channel bed, this means considerable labour and risk of error, whilst an assistant

is needed for the stop-watch. This last method is best suited to flumes and artificial channels of constant cross section, where a plank or two can be laid across a bridge for the observer carrying the meter.

The point method has been found to be the more accurate, as compared with integration methods, provided that the conditions are good, and that the observations taken are sufficient in number.

In integration methods, the observer is liable to bring the meter into contact with beds of weeds growing at either side of the river near the banks.

It must be borne in mind that the velocity obtained by the integration method is the resultant of the velocity of the water, and of the speed with which the meter is carried through the water by the observer, it must, therefore, always be greater than the true velocity.

Integration methods are useful in checking single point methods, and American engineers have found that the vertical integration plan gives better results than the single point method, at a bend in the stream, under ice, floating logs, or where the conditions are poor.

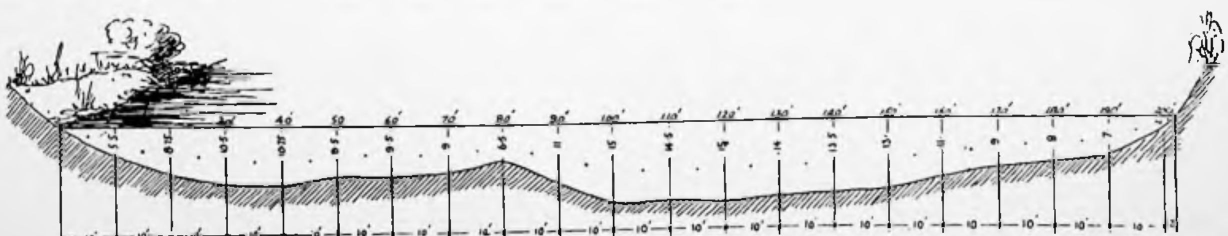
In all cases, the most accurate results will be obtained if the meter is held by a cord.

In the Cornell experiments the times required for the different methods of using the meter were as follows:—

Method	Time required (minutes)	Ratios
Ordinary method	30–60	6–6
0·6 method	20–30	4–3
Integration method	5–10	1–1

In the case of the ordinary point methods the meter is usually read for from 50 to 100 seconds each at all selected points and, if they do not agree, to take a third or even a fourth reading, until it is ascertained whether the discrepancy, if any, was due to temporary irregularity in instrument. If the observations have equal values, the average of the readings is taken, doubtful readings being rejected.

1	2	3	4	5	6	7	8	9	10	11	12	
Distance from initial point	Depth at sounding vertical	Mean sectional depth	Mean sectional width	Mean sectional area	Distance from initial point	Depth of centre of meter below surface	Duration of observation	No. of revolutions	Velocity at depth of observation	Mean velocity in sectional area	Sectional discharge	Remarks
Ft.	Ft.	Ft.	Ft.	Sq. ft.	Ft.	Ft.	Secs.		Ft. p. sec.	Ft. p. sec.	C.f.s.	
0	0	0	0	0	—	—	—	—	—	—	—	
10	5·5	2·75	10	27·5	5	1·65	54	5	0·25	0·25	6·875	
20	8·75	7·12	10	71·2	15	4·27	52	10	0·48	0·48	34·176	Date.
30	10·5	9·62	10	96·2	25	5·77	45	10	0·55	0·55	52·910	Place: Fledborough.
40	10·75	10·62	10	106·2	35	6·37	33	10	0·73	0·73	77·526	River: Trent.
50	9·5	10·12	10	101·2	45	6·07	47	20	1·01	1·01	102·212	Time: 9·3 a.m.—12·30 p.m.
60	9·5	9·5	10	95·	55	5·7	46	20	1·03	1·03	97·85	Gauge height: No change in river stage
70	9·	9·25	10	92·5	65	5·55	45·2	20	1·05	1·05	97·125	during gauging.
80	6·5	7·75	10	77·5	75	4·65	33	20	1·42	1·42	110·050	Meter used: Small Price electric current
90	11·	8·75	10	87·5	85	5·25	53·6	30	1·32	1·32	115·500	meter No.
100	15·	13·	10	130·	95	7·8	52	30	1·36	1·36	176·80	Method employed: 0·6 depth.
110	14·5	14·75	10	147·5	105	8·85	48	30	1·47	1·47	216·825	Suspension of meter: Cable.
120	15·	14·75	10	147·5	115	8·85	54	30	1·31	1·31	190·225	Wind: Calm.
130	14·	14·5	10	145·	125	8·7	54	30	1·31	1·31	189·95	Conditions: Channel hard, clay and
140	13·5	13·75	10	137·5	135	8·25	56·5	30	1·25	1·25	171·875	sand, very few weeds.
150	13·	13·25	10	132·5	145	7·95	40	20	1·18	1·18	156·350	Other remarks: River stage consider-
160	11·	12·	10	120·	155	7·2	41	20	1·15	1·15	138·	ably above normal.
170	9·	10·	10	100·	165	6·	41·6	20	1·14	1·14	114·	Intermediate soundings taken at each
180	8·	8·5	10	85·	175	5·1	50·6	20	0·94	0·94	79·90	meter point.
190	7·	7·5	10	75·	185	4·5	30	10	0·80	0·80	60·	
200	2·	4·5	10	45·	195	2·7	54	5	0·25	0·25	11·25	
202	0·	1·	2	2·	201	0·6	58	5	0·24	0·24	0·48	
—	—	—	—	2,202·	—	—	—	—	—	—	2,200	= 1,188,000,000 gals. per 24 hours.



Points at which meter was held . • 6 depth

In some cases it is preferable to make the observation last a complete number of revolutions rather than a given number of seconds, since this avoids fractions of a revolution of the meter wheel.

The individual observations to determine a vertical velocity should be extended beyond 100 seconds each if circumstances and time admit this.

Forms of field books for current meter work vary to the taste of the individual hydrographer.

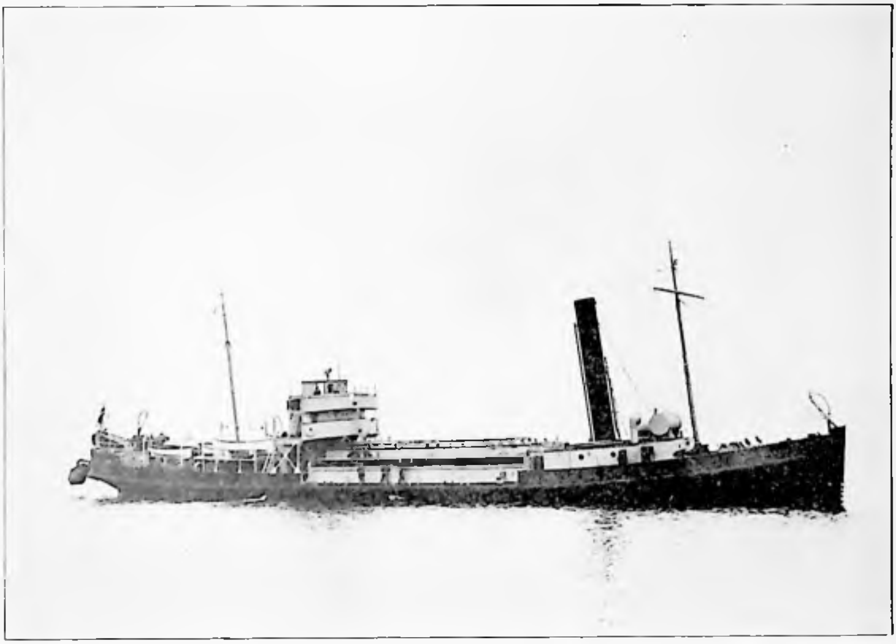
The table (page 69) shows a form in very general use. The data contained in the table refer to a discharge measurement of the River Trent. The diagram shows the cross section and the points at which the meter was held.

Some observers hold the meter at each vertical where a sounding is taken, and take the mean of the two verticals as the mean in the section. The writer prefers—where the soundings are quite accurate—to take the meter readings midway between the two verticals and to record the depth at that point, then the mean depth of the two verticals, multiplied by the distance between them, and also by the meter reading in feet per minute, gives the discharge in c.f.m. for that particular section.

In order to arrive at a satisfactory current meter discharge measurement, it is essential that the cross section of the river at the point of measurement shall be accurately known, and it will be as well to deal with this matter before going further. For current meter stations, as distinguished from "float" and "slope" stations, only one cross section is needed, namely, the actual in which the meter measurements are taken. This fact alone is a great point in favour of the current meter.

For "float and/or slope" work, not only are cross sections needed at the beginning and the end of the selected length of river, but several intermediate cross sections; frequently a large number if the reach concerned is a long one and extreme accuracy required.

Each permanent gauging station, where the river bed is



Stern-fitted Sand-Pumping Dredger *Annie W. Lewis.*
(*See page* 70.)

hard or fairly so, should have a standard cross section of the river prepared, which can be checked by subsequent soundings, and showing the contour of the channel to points on either bank above extreme high water level.

The standard cross section should be made by taking soundings at regular intervals across the river or stream during a period of low water. Since, however, the stage or height of the river will, on occasion, be considerably above the level at which the first series of soundings were taken, it is necessary to continue the contour lines of the river bed up the banks on either side to a height which will include, if possible, moderate floods. This can be done by employing a level and taking the contours of the banks at, say, each foot of gauge height.

Soundings taken during periods of heavy flows and high velocity may very easily be erroneous, and if the method just described of developing the cross section up to and including the river banks is followed, the cross sectional area corresponding to any period of high water can easily be found, after any particular flood gauging has been carried out, without the loss of time, let alone probable error which would result if the soundings were synchronised with the gaugings.

After floods, it is, of course advisable to check the low water soundings, and also to see whether any obstacles, such as submerged trees, etc., have been brought near the cross section.

The selection of the spot for the cross section is dealt with in the section on gauging stations, it may not be amiss to point out here that it is often a matter of days before a really suitable length of river and cross section can be decided upon. The whole of the bed must be gone over up and down the river, and possibly just when a suitable locality seems to have been secured, it will be found that there is an old sunken barge, or some similar obstacle, which would vitiate the results. This difficulty is, however, not so likely to occur with a meter section as with float or slope sections, owing to the relatively greater length of these latter.

The usual procedure followed in taking soundings is,

in the case of small or moderate sized streams, to extend an ordinary tape from bank to bank at a height of about 3 feet from the surface of the stream. The tape can be held by light iron supports, a saw cut in the tops of them holding the tape edgeways to any wind there may be, in addition to making it more easily read in this position; the exact position of each sounding can then be located.

In the case of streams over 20 feet, or so in width, in order to prevent over stretching of the tape, and to still it, a wire is usually run across the stream and the tape fastened to this at intervals.

If the stream is shallow enough to wade and has a hard bed, soundings can be taken most accurately in this fashion.

It is of the utmost importance that the stage or height of the river should be carefully watched whilst the soundings are being taken.

This can be done by noting the height of the water on the gauge, or should there be no gauge, a peg can be pushed into the margin of the river and a round headed nail driven into it level with the water surface.

The point at which soundings commence is usually termed the "initial" point, and this point should be referred to some permanent feature on the bank, so that it can be readily identified subsequently. A tree trunk is often available, or some structure or other. If no such object is present, a stout post should be driven in almost level with the ground on either bank, exactly on the line of the standard cross section, and supplementary posts should also be driven into the bank at a higher level, on the line of cross section.

As regards the intervals at which soundings should be made, it is usual to take them at distances of from 10 to 25 ft. apart in the case of larger rivers; of from 2 to 5 feet apart or less where smaller streams are concerned. It should be carefully borne in mind, however, that in the case of large rivers the beds are not often visible, and it is therefore safer to take soundings at intervals of 5 feet, in order to find out any abrupt

alterations in cross section, should these be present; much however, must be left to the discretion of the observer. The velocities can still be taken in 10 ft. or 20 ft. sections, unless marked irregularities are disclosed. In the case of very large rivers, which do not occur in this country—and with estuary gauging, which comes under another category—soundings must be carried out with a boat or launch, ranging poles, and theodolite or sounding sextant.

With wide deep rivers, where the use of a boat is obligatory, it is advisable to stretch two stout wires across from bank to bank about 3 to 4 feet apart, the up stream wire being divided into 5 feet intervals, numbered tags being attached to the wire every 5 feet. Nurserymen's zinc labels answer well for this purpose. The downstream is used to steady the boat's head against the current, whilst the observer in the bows of the boat takes the soundings from a position between the two wires. The wires should be removed before the discharge gauging is complete; they should never be left in position overnight.

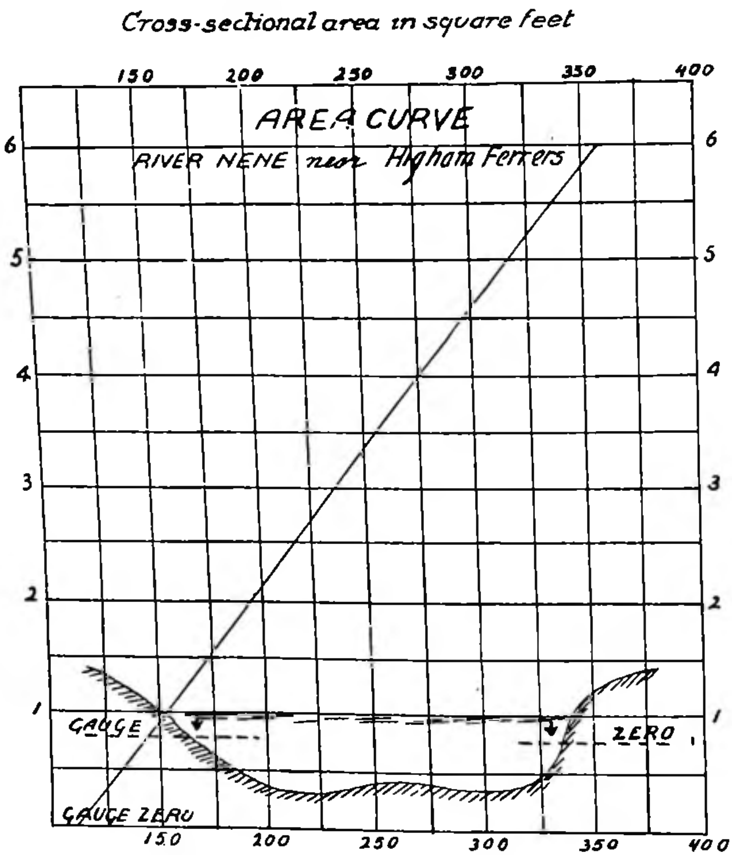
In the case of rivers on which there is much traffic, it is often best to carry out gauging on Sundays, and in addition irregularity of flow and complications.

The passage of steamboats is apt to vitiate current meter readings for some time, both before and after their passage. Current meter observations should only be taken from a boat on calm days unless the meter has been rated under similar conditions, *i.e.*, as regards oscillations. The bows or prow of the boat should be fairly sharp, and the meter used from the end of a short length of spar, projecting some 2 or 3 feet beyond the stem of the boat, after the fashion of a bowsprit.

Soundings made from a boat can be carried out by two persons, one managing the boat, etc.

The diagram on page 74 shows a cross section of the River Nenenear Higham Ferrers, and the area curve derived from it. The curve is obtained by ascertaining the area of the cross section corresponding to each foot or half foot of the gauge, from the zero mark upwards, as far as may be desirable.

Gauging Stations.—With regard to the establishment of gauging stations, these may be described as (1) permanent, (2) non-permanent; these latter being as a rule stations supplementary to the permanent ones, and only intended for use during exceptional conditions, *e.g.*, during droughts. The work



carried out at permanent stations consists mainly in recording the daily stage of the river, the taking of cross sections measurement of the discharge at various stages, and the calculation of the discharge of the river at each stage. This latter work, however, is not necessarily carried out at the gauging station.

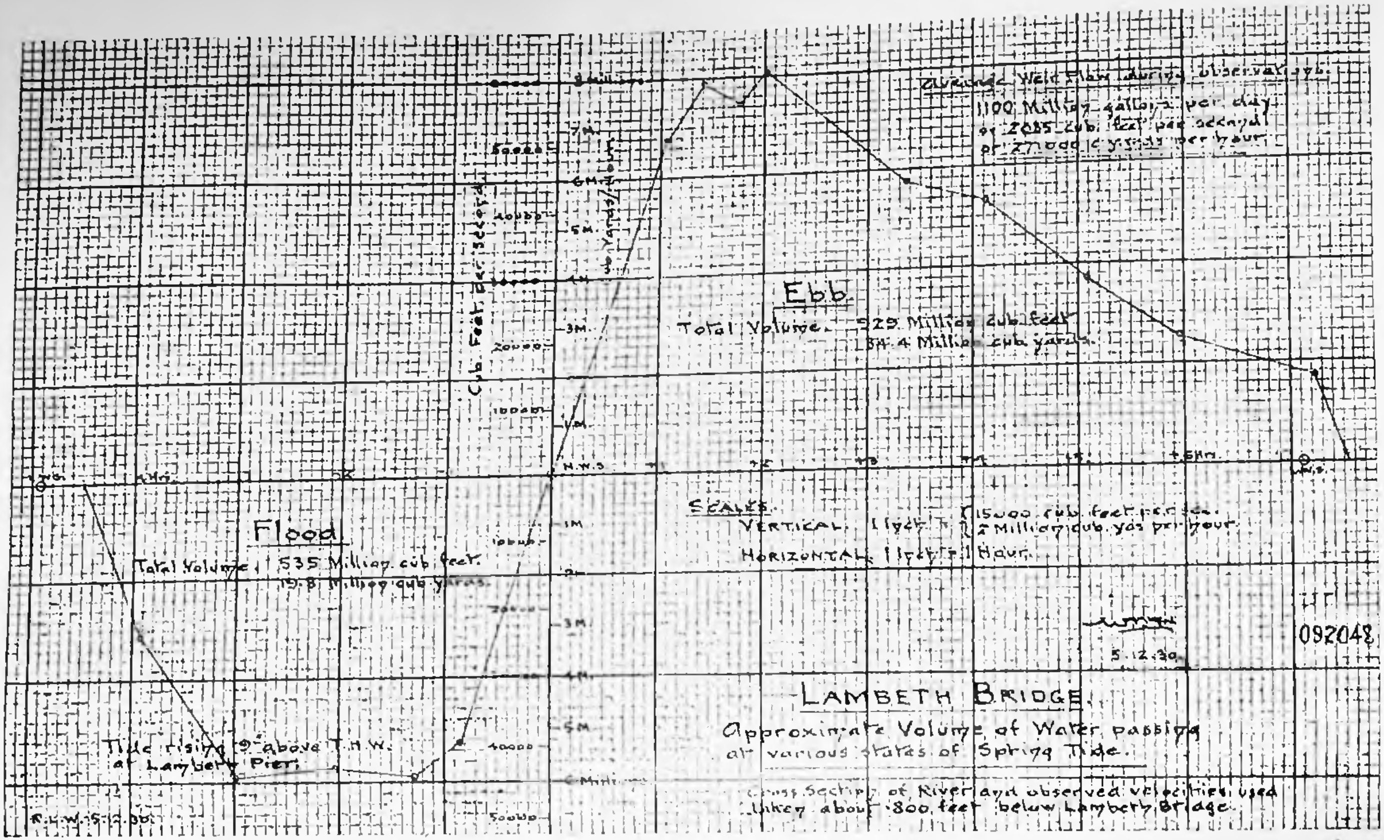
In order to arrive at the yearly flows of rivers and streams,

and their seasonal distributions, two things are wanted: daily records of stage and the discharges which correspond to these daily variations. From occasional meter measurements a discharge curve can be plotted, such as is shown in diagram (page 76), and from a discharge curve tables can be constructed showing the discharge for each tenth of gauge height. This will be dealt with later.

In order to avoid interpolations which may on occasion be erroneous, great care should be exercised in choosing the permanent station, so as to avoid as far as possible gaps in records.

Since for accurate discharge measurements it is necessary to have certain conditions, suitable sites for gauging purposes are often difficult to find; their number, too, is often further limited by reason of the face that they must be within reasonable distance of the home of the gauge reader. As regards necessary conditions, the channel of the river should be straight for 100 to 200 feet above and below the gauging station, the precise distance depending upon the size of the river and other factors; the channel should also be fairly uniform in cross section and free from obstruction and weeds; there should be no sudden changes in velocity, no back watering due to tributary streams entering just below the gauging section; and the bed of the river, if a small one, should if possible have no projections of more than 3 to 4 ins. above its general contour.

The river bed should be permanent, but not stony and not liable to scour; whilst if high water discharge records are needed, the banks should be fairly high and the spillways deep. Sandy channels liable to shift should be avoided, owing to the trouble they involve by requiring almost constant checkings of the cross section. Cross sections should also be avoided near the mouths of rivers subject to tidal influence, and also sections of streams below mills causing unequal flow. Finally, whenever possible, a cross section should be chosen where a good measurable velocity will exist at all stages of the river. If this last condition can well be complied with in dry weather, it is often


Average Weir Flow during observations.
1100 Million gallons per day
or 2085 cub. feet per second
or 270000 c. yards per hour.
Ebb
Total Volume. 925 Million cub. feet
34.4 Million cub. yards.
Cub. Feet per second
Cub. Yards/Hour
Flood
Total Volume, 535 Million cub. feet.
19.8 Million cub. yards.
H.W.S.
L.W.S.
Scales.
Vertical. 1 inch = 15000 cub. feet per sec.
2 Million cub. yds per hour.
Horizontal. 1 inch = 1 Hour.
Tide rising 9" above T.H.W. at Lambeth Pier.
Lambeth Bridge.
Approximate Volume of Water passing at various states of Spring Tide.
Cross Section of River and observed velocities used taken about 800 feet below Lambeth Bridge.
5.12.30.
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convenient to have a supplementary gauging station, with a small cross sectional area for use during dry weather flows. Where two such stations adjoin it is sometimes useful to obtain daily surface slope records, the zero of the gauges at each station being referred to bench marks.

It is quite essential to lay stress on the foregoing points, since a current meter measures, roughly speaking, any curved thread in the current which meets the wheel; and, if the direction of the current varies very much, as for example in a rough channel, inaccurate results will be obtained no matter what type of meter is used.

The small type Price meter, it may be observed, measures both horizontal and vertical motion and also cross currents. If the river at the gauging station is shallow, meter measurements can be carried out by wading at low water stages. If the water is too deep for wading a boat will have to be employed, unless a bridge or a cable ferry can be utilised. It may be noted that bridge stations, or cross sections near bridges, are, as a rule, to be avoided, since the piers distort the natural flow of the stream, altering the vertical and transverse velocity curves, thus rendering them of local value only. In America, what are known as cable stations are employed where the span of the river is less than about 500 feet; the cable, if a permanent one, should be high enough to admit of observations being made during floods. For spans of 100 to 300 ft., $\frac{5}{8}$-in. galvanised wire cable has been used with success, a $\frac{1}{2}$-in. cable sufficing for spans of less than 100 ft.

In the foregoing notes on river gauging, reference has been made to the "Price Electric Current Meter." We therefore present the principles of the British current meter of the same type known as the "Watts" Current Meter, as used at the present time. We have had personal experience with this meter and can speak highly of it.

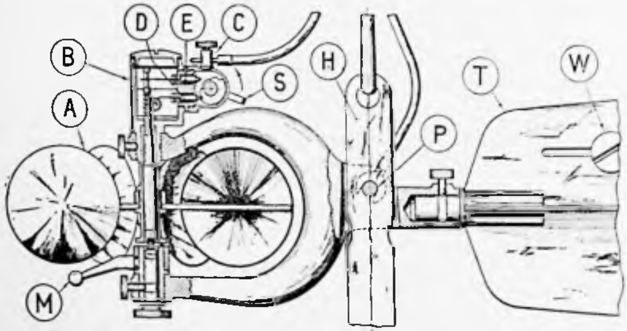
Its description is as follows:—

The current meter is supplied with two methods of suspension in water:—

No. 683 with long cable, for use in deep water.

No. 684 with rigid metal rods for shallow streams.

The bucket wheel *A* (*see* diagram) is arranged so that it lies horizontally in the water. The flow of the stream revolves the wheel and the number of the revolutions is indicated by means of an electrical device *B*, which indicates by a click either each individual revolution *E*, or if desired, every fifth revolution *D*. The electric current producing these clicks is transferred by an insulated wire inside the suspension cable to a head phone, and with the help of a stop watch the number



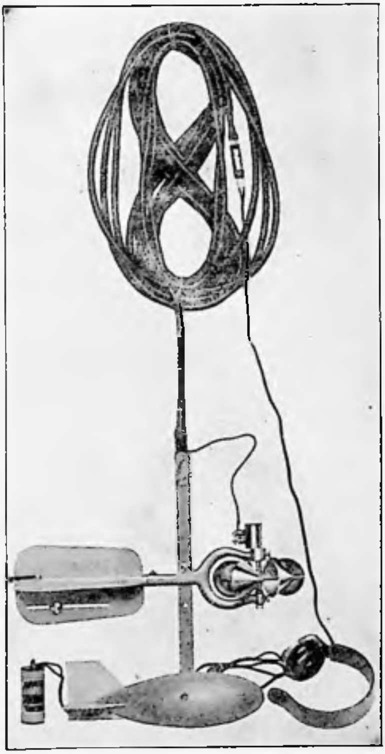
"Watts" Current Meter.

of clicks heard in a given time can be counted. By reference to the rating chart attached to the lid of the box, the velocity of the water in feet per second can then be ascertained. For streams of low velocity each individual revolution should be counted, and for streams of higher velocity every fifth revolution. This is controlled by moving the switch *S* from one position to another.

For current meter No. 683, a lead weight of stream-line design is attached to the hanger *H* for the purpose of steadying the instrument and keeping it in position. These weights are made in various sizes to be used as required in water of different velocity or, if desired, two weights can be attached at the same time to the hanger *H*.

As it is essential that the bucket wheel shall rotate with as little friction as possible, great care has been taken that all the parts are most carefully balanced: the pivot is made of hardened steel, the bearings being of sapphire.

A safety catch *M* is provided for clamping the bucket wheel when not in use. It will be found impossible to close the lid of the case unless this catch is in operation.



Current Meter with Cable Suspension No. 683.

For the purpose of keeping the instrument in a constant direction to the stream, a tail piece *T* is attached. This has a small weight *W*, which can be adjusted for balancing the tail piece with the instrument when it is suspended.

Dredged Channel Curves.

Their Relation to the Turning Circle of Ships.—The engineer embarking on the development of a river or tidal waterway by means of dredging may have to consider the radius of the curve or bend to which he will align the channel, having regard to the turning circle of the ships which not only will use the channel on completion of dredging, but he may also have to provide for the growth in dimension of the shipping using the waterway and consequently future accommodation in channel depth.

The natural tendency in river channels is to form a series of deep water pools on the concave sides of the bends, with shallows at the intervening positions where the current passes over from one side of the stream to the other.

In tidal rivers the flood tide complicates these conditions, but generally has the effect of creating a pool on the opposite or reverse curve, and thus there are usually two pools in the same reach with a crossing or shoal area between them. The foregoing formations are especially common to embanked rivers or tidal waterways having a sinuous watercourse. To improve these hydraulic and hydrographic conditions there are now several methods adopted. We do not intend to do more than enumerate them here.

(1) Embanking and groyning the natural channel.
(2) Canalising and pool filling (practised in Holland to maintain a level bottom by means of mattress work).
(3) Riveting, *i.e.*, constructing dykes which train the channel below half-tide level.
(4) Dredging accompanied by above methods of channel training, or alternatively, without any artificial aids.

It is now many years since Mr. Girardon advocated at the Sixth International Congress of Navigation the retention of the sinuous watercourse in rivers with gentle slopes at the pools

and steeper ones at the bars, and to create the improvement by converting poor crossings whenever they occurred into good ones, the result to be obtained by giving a *suitable direction to river currents across the bars.* When combined with the investigations of Mr. Fargue on the "Influence of Bends on Channel Depths," it led to a new conception of the proper functions of the works constructed to improve channels.

The direction which the works of contraction gave to the confined waters became of more importance than the relative amount of contraction, and could be given such a direction as to produce the proper effect on the bars or crossings.

When this method is followed, the sinuous course of the river is preserved and even intensified. *It is to this limit of channel curvature which can be adopted that we would draw attention in these pages.* In *Kempfe's Engineer's Year Book* (1917), 24th edition, reference is also made to this matter, and it is stated that, generally speaking, for vessels of 400 to 500 tons moving at a fair rate of speed a radius of 500 yards should be regarded as a minimum—at low speeds 200 yards will suffice for radius of curvature. The minimum for vessels of very small tonnage (say under 200 tons) may be as low as 66 to 88 yards. It will be obvious, however, that in addition to the radius, speed and tonnage factors there are others; for instance, the draft of the vessel is important as it governs the ratio of displacement or cross section of vessel to cross section of channel.

Mr. G. S. Baker in his work, *Ship Form, Resistance and Screw Propulsion*, deals fully with the relation of ship to channel, which the channel designing engineer should study to fully appreciate. He explains that, in restricted water channels, if a vessel is passing through a channel of gradual constriction, the cross section of the stream lines around the ship must also be gradually reduced, *and the changes of velocities and pressures must therefore be increased.* In shoal water the conditions become more favourable for eddy making. Professor Havelock has also shown that a travelling point

of pressure creates waves of greater divergence in shallow than in deep water, and this *divergence* increases with speed, and ultimately at a critical speed they are all concentrated in a large transverse wave somewhat similar to a wave of translation. Above this speed only *divergent* waves are possible. The critical speed is given by $V^2=11{\cdot}5\times d$, V being speed in knots, d the depth of water in feet.

Schutte has tested several ship forms in channels of varying width and depth and in what may be called open and unlimited water. Take first the case of the cargo boat. The increase in resistance at any speed over the open water value was approximately the same for a broad shallow channel as for a narrow and deep channel, *provided* the ratio $\frac{\text{depth of water}}{\text{draft of ship}}$ in the former and $\frac{\text{width of channel}}{\text{beam of ship}}$ in the latter were the same. This only applies to the ordinary low speeds at which such a vessel would run, when wave making is not very important. Over this range of speed the percentage increase of resistance was roughly constant for any given size of channel. The result of several experiments show that in a confined channel the deep vessel suffers more than the shallow one, and that a cross section area of channel about 200 times that of the vessel is required at all normal speeds if the resistance is not to be affected by the boundaries. At low speeds a smaller size can be allowed, the necessary ratio of areas being about 150.

It has been shown that there must be a depth of water equal to 14 ft. to 7 ft. drafts when there are no side boundaries, and a breadth of channel equal to 10 ft. to 8 ft. beams when the water depth is very great. When both side and bottom boundaries are present these numbers naturally increase somewhat.

Behaviour of a Ship under Speed and Helm.—In practical navigation when it is found that the depth of channel accompanied by width and curvature of channel are such as to make steering uneasy or the vessel unresponsive to the helm, two

actions may be taken: (1) If the vessel has twin or multiple screws the speed on one set of engines can be eased or stopped and the other increased thus imparting a better turning movement to the ship; (2) if the vessel is a single screw vessel or of the larger dimensions with twin or multiple screws it becomes advisable, in practice, to make a tug fast ahead to assist in the navigation of such bends.

A vessel when turning under the influence of helm and engines only—that is to say, the propeller or propellers working to force the vessel forward—behaves in a manner now properly defined.

The vessel usually turns or pivots on a point well forward in her middle line, and the curve described by the centre of gravity of the ship is slightly outside the circle described by the stem or forefoot. The centre of gravity in fact travels outward immediately from the line of original course, when the helm is put over, and the stem of the ship is involuntarily carried into the channel if the vessel is on the starboard side of the fairway and the vessel under starboard helm. The maximum distance that the ship's centre of gravity travels in her original direction after the helm is put over is termed the "advance." For an approximate investigation of the forces in operation during the turning of a ship the motion may be divided into three stages.

(*a*) When the rudder is first put over and the pressures on the hull are those which produce angular acceleration.

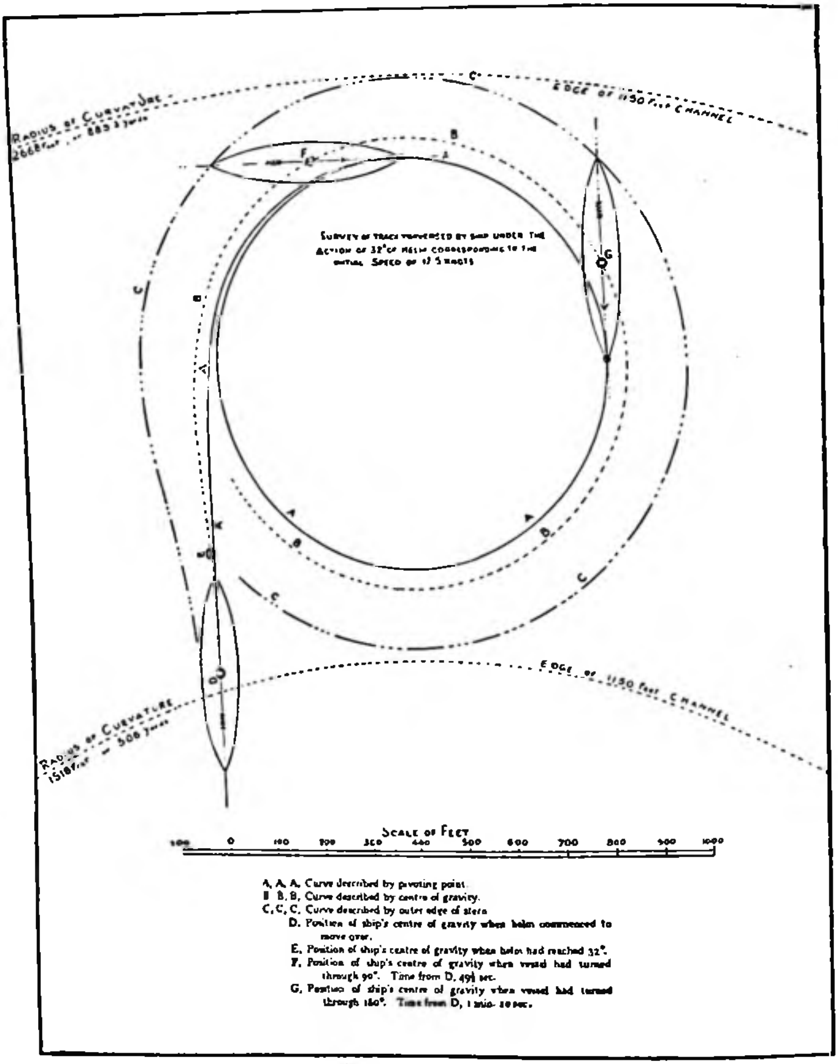
(*b*) When the accelerated forces are combined with those caused by the resistance of the ship to rotation.

(*c*) When finally turning uniformly in a circular path.

The character of the forces acting during stages (*a*) (*c*) can be ascertained, and the type of motion under the complex represented by (*c*) will consist of a gradual replacement of the motion at (*a*) by that at (*c*). (*See* diagram turning circle on page 84.)

Now the problem before the hydrographic officer or engineer

is to provide a curve with as convenient a depth and stream line flow as nature will permit. Water in flow tends to hug the concave bank in sympathy with the pool formation.



When resistance increases by the combination of ship form and channel form to an extent which makes the navigation difficult for large vessels, channel rectification by dredging or re-alignment may be desirable.

We have found that a decrease in the radius of curvature of a dredged channel previously having a mean radius of 1736 yards to a mean radius of 1389 yards has improved rather than restricted the manoeuvring of large vessels by (*a*) increasing the water area permanently by adoption of the pool area on concave side; (*b*) leaving the convex point or salient in repose which has the beneficial effect of cultivating a more natural stream line, and producing better channel maintenance above and below the salient.

To crystallise the matter of dredged curves at bends in rivers tidal or non-tidal, we have therefore to consider:

(1) Size of vessels and whether twin or single screw.

(2) Facilities for assistance around bends by tugs.

(3) To what extent the known factors of cross sectional area of channel to cross sectional area of ship will operate in the bend or curve under consideration.

(4) Hydrographic conditions upstream and downstream of the bend or curve under consideration.

There remain also for study in this connection the theories and experiments of Professor James Thompson regarding the formation of pools and salients at bends in rivers, flowing under the action of gravity to the sea.

Professor Jas. Thompson pointed out (Proc.Roy.Soc. 1877, Proc.Inst.Mech.Eng. 1879, page 456) that the usual supposition is that water tending to go forward in a straight line rushes against the outer bank and scours it, at the same time creating deposits at the inner bank. That view is an incomplete account of the matter, the Professor having given a more ingenious account of the action at the bend, which he completely confirmed by experiment. Thus when water moves round a circular curve *under the action of gravity only*, it takes a motion like that of a free vortex. *Its velocity is actually greater, parallel to the axis of the stream at the inner side than at the outer side* of the bend. Hence the scouring at the outer side and depositing at the inner side of the bend

are not due to mere difference in velocity of flow in the general direction of the stream but in virtue of the centrifugal force, the water passing round the bend presses outwards, and the free surface in a radial cross section has a slope from the inner side upwards to the outer side. For the greater part flowing in curved paths, this difference of pressure produces no tendency to transverse motion. But the water immediately in contact with the rough bottom and sides of the channel is retarded, and its centrifugal force is insufficient to balance the pressure

FIG I

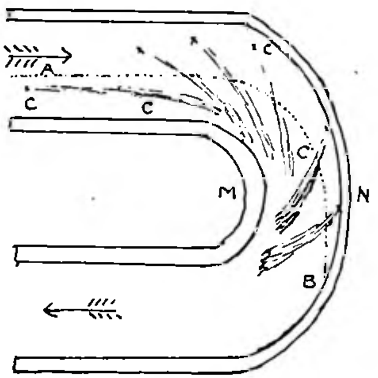
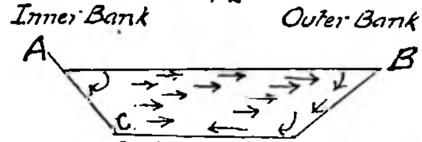


FIG. 2

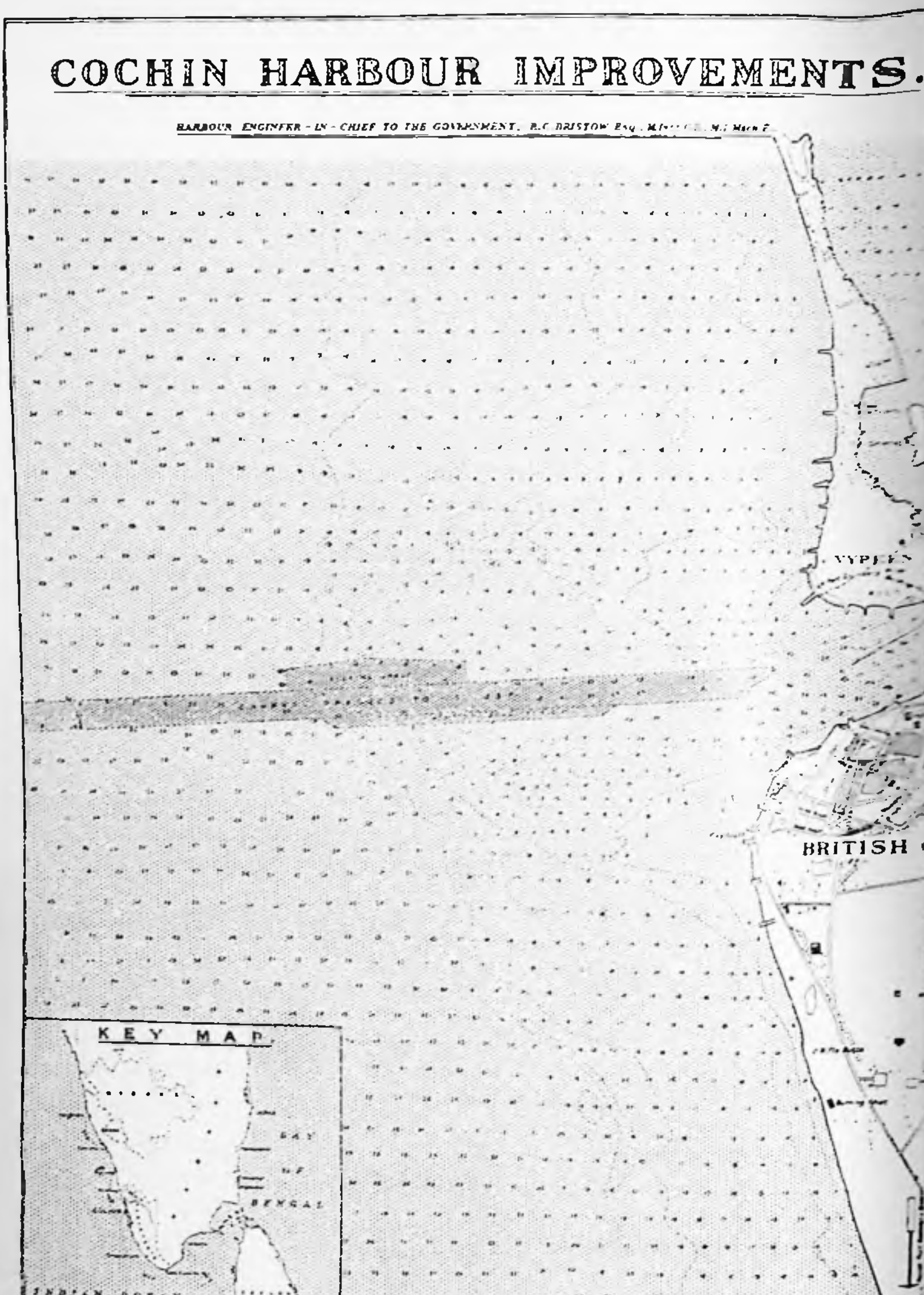


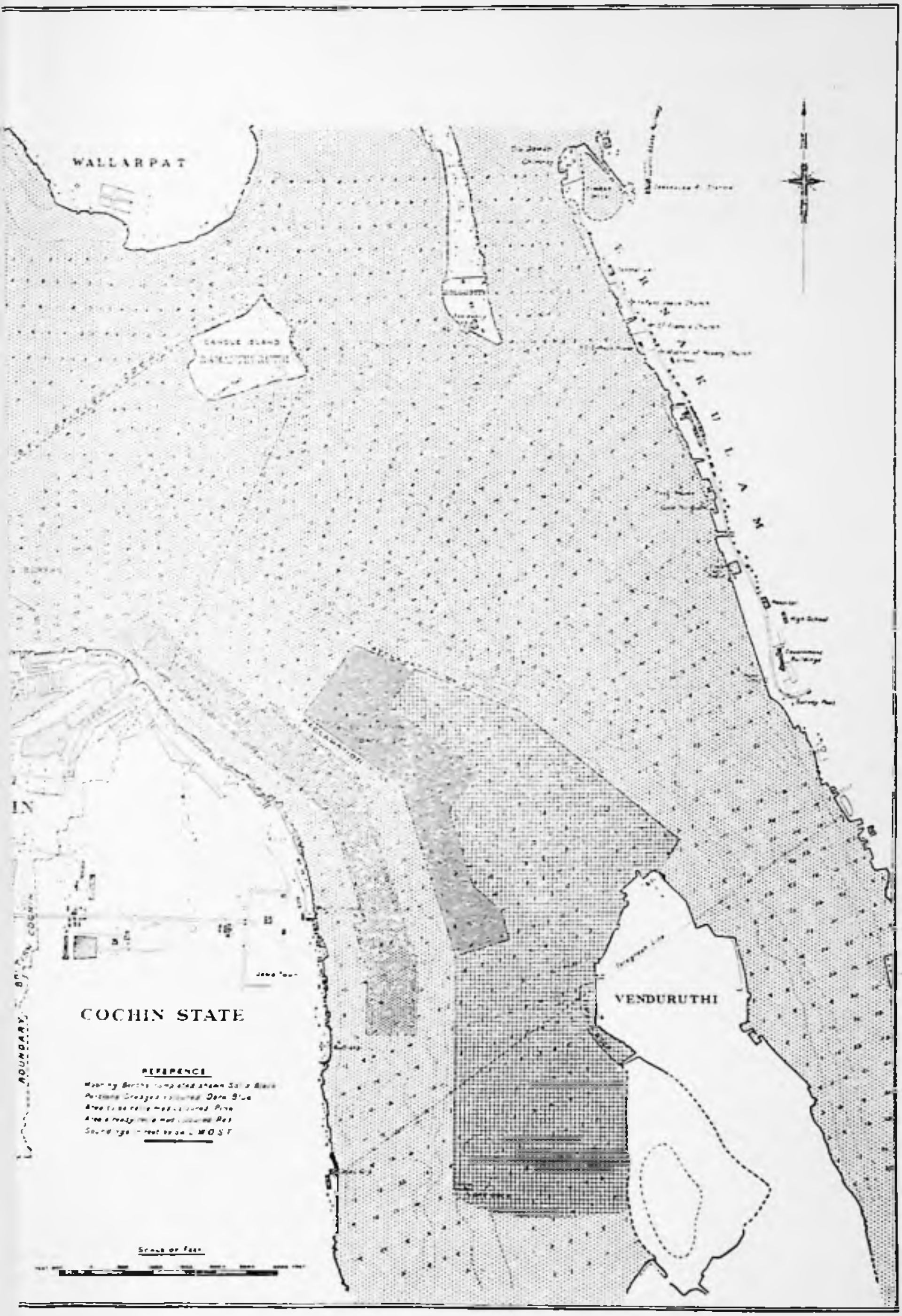
Section at M.N

Thomson: River bend circulation and flow

acknowledgement to Encyclo Brit 13th Ed. 1926

due to the greater depth at the outside of the bend. It therefore flows inwards towards the inner side of the bend, carrying with it detritus which is deposited at the inner bank. Conjointly with the flow inwards along the bottom and sides, the general mass of water must flow outwards to take its place. Our figure showing the directions of flow in a small stream, the lines CC show the direction in contact with sides and bottom. The dotted line AB shows the direction of motion of floating particles on the surface.


COCHIN HARBOUR IMPROVEMENTS.
HARBOUR ENGINEER - IN - CHIEF TO THE GOVERNMENT. R.C. BRISTOW Esq.
BRITISH
KEY MAP.
BAY
OF
BENGAL
INDIAN OCEAN



To face page 86.

Professor Thompson's observations were obviously directed more to curvatures sensitive to scour, but in tidal rivers with pitched embankments the same conditions may apply on the ebb tide at certain bends, the velocity being greater at the inner side of the axis than at the outer side, and the duration of ebb tide being the dominating period of flow.

CHAPTER III.

RIVER TIDES.

River Tides.—One may almost know on looking at a map whether the sea into which a river discharges itself be tidal or no. The form of the mouth is essentially different in the two cases.

Compare on the map of France the Rhone and the Loire rivers of about the same class. In the case of the Rhone, the river before it reaches the sea is divided into two great branches, and these again are subdivided into others. The Loire has but one mouth, and that one of great width and a taper form.

The Rhone is but a type of all the Mediterranean rivers; the Loire is exactly like the Gironde, the Seine, the Thames, the Severn, and the Elbe. In America we have the Mississippi like the Rhone on a vast scale, the St. Lawrence with a long bill mouth, and the Amazon with two mouths, it is true, but each like the mouth of the Loire, wide and taper. The Indus and Ganges have each several months, but they are all of a taper form.

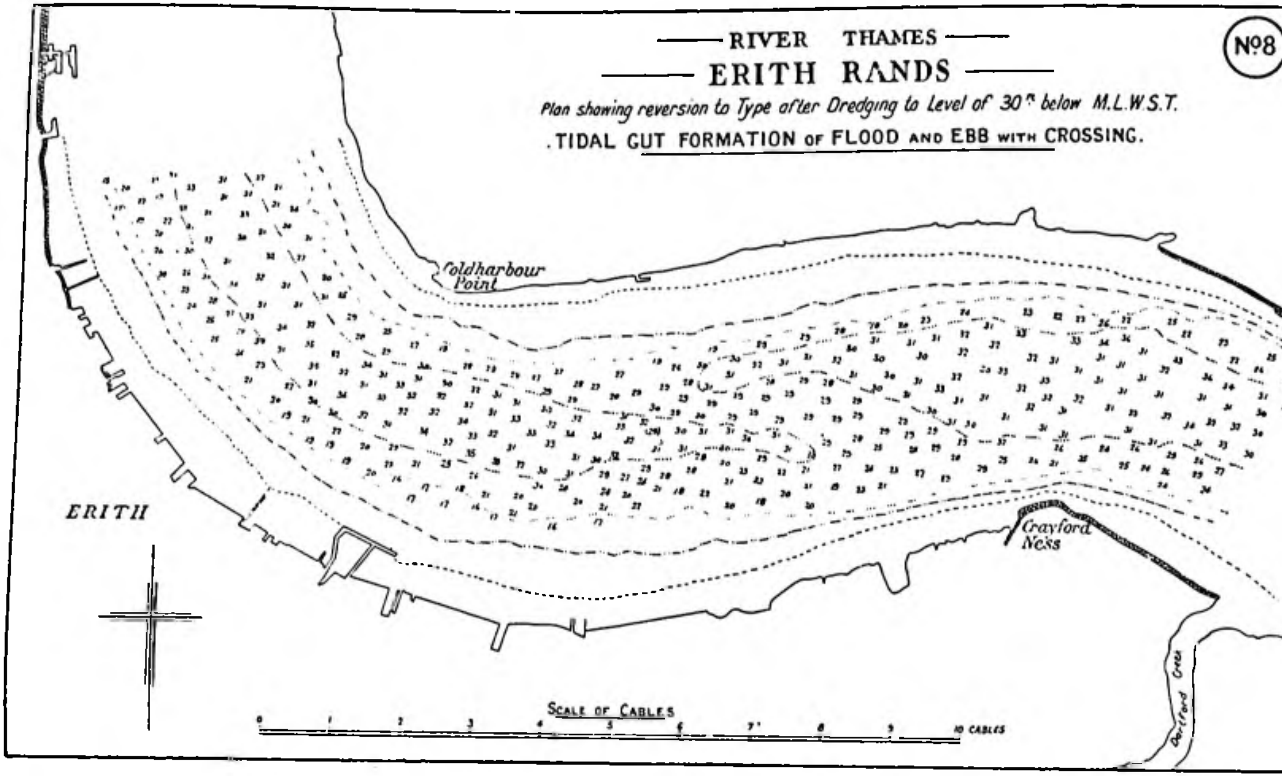
Now a river is great in proportion to the quantity of water it discharges, and the mouths of tidal rivers are so much larger than those of rivers of the same class without tide, because they have to discharge not only the land water but the tidal water which periodically flows in.

Of all the water that passes under London Bridge upon the ebb of a spring tide, only about one-twelfth is land water, the remainder being entirely tidal water; and consequently the port of London has the benefit of a river twelve times as large as it would be if there were no tide, or even if the tide were stopped by a dam at London Bridge. At Gravesend

the proportion of tidal to land water is very much greater, and nearer the mouth it increases still more. Now observe the effect of this. The discharge of water being greater as we descend the river, the channel is necessarily greater to admit of it, and consequently the effect of the tide is to create a taper or funnel mouth. On the other hand, this taper or funnel mouth is just the form which encourages a greater rise of tide, and thus the quantity of water to pass in and out is again increased, and the funnel is still more enlarged. The two operations assist one another, and we see the effect, in the large widely expanded estuaries into which our tidal rivers discharge themselves.

On the other hand, look at the effect of the fall of a river into a tideless sea. The size of the river increases, it is true, as it descends, because more water drains into it, but the rate of increase is vastly less than in the case of a tidal river, and towards the mouth especially it is slow, so that the river, where it joins the sea, is practically of the same size as at a distance of 20 miles up.

But although the amount of water is nearly the same, the circumstances in other respects are very different. Every river brings down with it a quantity of earthy matter, sand or mud. Even when the water appears perfectly clear there is generally a slight movement of the lighter particles of earth in the bed, and when the river is swollen with rain every one knows how turbid it becomes. Now it is a law of running water that the more rapid the stream the greater the quantity of solid matter which it can carry with it, and the heavier and coarser will be the nature of the earthy particles. Thus a stream of a certain velocity will sweep along pebbles, a less rapid one fine gravel, another sand, and a gentle stream will hardly hold fine mud in suspension. It will be easily understood that when a stream is checked, either by entering a pool of still water, by an enlargement of the channel without a corresponding increase of the quantity of water to be discharged or by entering the sea, the solid particles, which the water in



RIVER THAMES
ERITH RANDS
Plan showing reversion to Type after Dredging to Level of 30 ft. below M.L.W.S.T.
TIDAL GUT FORMATION OF FLOOD AND EBB WITH CROSSING.
No. 8
Coldharbour Point
ERITH
Crayford Ness
Dartford Creek
SCALE OF CABLES
0 1 2 3 4 5 6 7 8 9 10 CABLES

a state of motion could carry along with it, will be deposited. So we find in most cases that a river, where it is narrow, is deep; where it is wide, its channel is encumbered with banks of sand or gravel which have been deposited there by the slackening of the current. Upon entering the sea the solid matter is naturally deposited, and thus a shoal comes to be formed just in front of the mouth of the river. In process of time this shoal increases, till at last it rises up to the water's surface, the stream being then divided into two branches. Each of these branches will become in course of time a channel similar to the main river, but of only half the size. The island formed between them will widen and lengthen and become dry land; it may indeed be cultivated and inhabited. Meanwhile, however, each of the river branches may again have become subdivided, and new shoals, islands, or "deltas," as they are called, formed. Then perhaps on some occasion of a violent flood, when the stream has attained a great velocity and an overwhelming power, it will not wait to be diverted into its numerous channels, but bursts over the delta and makes for itself a new straight channel out to sea. Then the original branches become more or less filled up as the current is diverted from them, and thus the spot which in the first instance was the river mouth is now many miles inland, or at the head of an archipelago of swampy alluvial islands. On a large scale this is the work of centuries, but it is always going on. The new channel forms another delta at its mouth; the same process is repeated; the river is divided and subdivided by the land it has itself formed. At the same time, the washing of the waves of the sea upon the light soil of which the new-made land is composed continually tends to widen the channels, and the new deposits continually tend to make them shallow. Thus nature is continually at work to deteriorate the mouth of a river and make it advance further into the sea.

These effects may be seen upon the map, which shews the mouth of every river discharging into a tideless sea to be situated on a part of the coast more or less projecting.

Now let us see how the mode of deposit from the water of a river is modified by the tide.

As far down as the point where the tide first becomes perceptible, the two rivers are in the same position; each brings its due quantity of earthy matter. In the case of the tidal river, however, the river water does not fall abruptly into the still waters of the sea, but it mingles itself with the running tidal water, and the two flow on together to the sea. The proportion of tidal water is continually increasing, the channel widens and deepens, but the stream does not slacken except for a short time at the change of the current. Thus, without any increase of the earthy matter, we have all the circumstances of a much larger river. We have the dimensions of the Nile with the quantity of deposit due to the Thames.

It may be observed as apparently inconsistent with this remark, that the waters of a tidal estuary are much more muddy than those of the river itself. This is true, but the great bulk of the mud is never permanently deposited. It is washed up and down by the flood and ebb; the only actual accumulation is the quantity brought down by the river itself, and though it must be ultimately deposited somewhere, its quantity is very small, compared with the size of the great tidal estuary into which it is carried, and to the vast volume of water which is constantly flowing over it.

Again, the deposit will be distributed over the length of the estuary, according as the tides are more or less strong, or as the river water bears a larger or smaller proportion to the tidal water, so as to give a more or less preponderance to the power of the ebb tide over the flood. Thus, while in the case of a non-tidal mouth the deposit is confined to the point at which the river actually joins the sea, or to a comparatively short distance beyond it, to which the momentum of the water may carry the earthy particles, in a tidal estuary the deposit may take place in any part between the highest limits of the tide and the open sea. In the one case a year's deposit will be a bed of small extent but considerable thickness; in the other a

very thin layer over a large area. Suppose then that two rivers, similar in all respects, were to discharge themselves into funnel-shaped bays of the same form, but one in a tidal, the other in a non-tidal, sea; how would the accumulation of ages affect each? In the non-tidal case, the accumulation would begin at the head of the bay where the current slackens; the form would become more and more blunted, but the lower end would remain unchanged till the deposit reached it in its regular course. In the tidal bay there would be a thin layer annually spread over the whole bay, or great part of it; some would be deposited at the head, but some would be carried to the mouth. From year to year the change would be imperceptible, but from age to age we should find the whole bay advancing a little seaward, but maintaining its form, or at least only changing it as inequalities were filled up, and the dimensions of the gradually enlarging channel adjusted to the gradually increasing quantity of water which it has to pass.

On the other hand, if the two mouths were in the first instance of parallel width, instead of funnel-shaped, and if the soil were of a nature to be moved by water, the tide would immediately work away at the sides and make for itself a funnel.

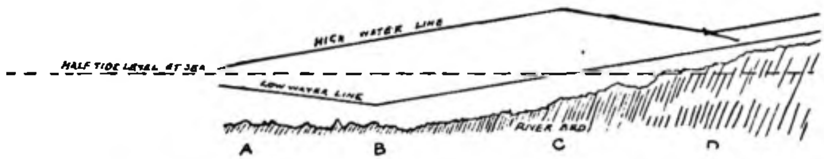
The form of a river mouth then depends upon the sea into which it falls being tidal or non-tidal. Where the sea is non-tidal, the river deposits form deltas, and the channels are divided and subdivided; where the sea is tidal the material for the deltas is dispersed or spread over a larger space, while the tide forms and maintains for itself a channel compared with the size of which the river deposits are insignificant.

Having now seen how a river mouth is affected by the tide, let us see how the tide wave is affected on its entrance into the river.

The channel of a river is in fact a gulf which is very long in comparison with its width. The quantity of water required, therefore, to form the tide wave is considerable, and its entrance occasions a considerable current to set up the river during the flood tide.

Near the mouth the current does not change with high water, but it follows the law of the sea tide, flowing up during the upper half of the tide and down during the lower half. In proceeding up the river, however, the times of the changes of current, and of high and low water approach nearer, and some miles up are generally very near together, though the stream generally continues a few minutes after high and low water before it stops and changes its direction.

The manner in which the range of the tide varies, as the wave passes up a river, will be best understood from the accompanying diagram.



The mouth of the river is at *A*, where the range of tide is that of the neighbouring sea. After entering the river the wave increases, both by high water being raised and low water being depressed, according to the ordinary law of a gulf wave, the mean or half tide level remaining nearly the same. This increase of range is well marked in some very long river mouths. At King Road, for instance, in the Bristol Channel, the level of low water is 12 to 14 feet below that of low water at sea, and the high water is as much above high water at sea. In the Mersey, low water a little below Ellesmere Port is some inches lower than at sea. This increases of range continues so long as the channel is sufficiently wide and deep to allow the full undulation of the wave. An estuary of considerable length and depth is required for this division of the tide to be manifested. In a small estuary, the length (*A B* in the diagram) will be much reduced, and perhaps *A* and *B* may come close together, so that no depression of the low water will be found.

Above the point *B* the character of the tide changes. Its channel can no longer be considered a branch of the ocean,

but is a river of running water, with a surface and bed naturally sloping towards the sea, and a current more or less strong opposing that of the tide. At first, however, the channel at high water is large, and the wave has room to develop itself to its natural size, which should be greater than at *B*, so the high water is higher up to a certain point, *C*; although at low water the channel has become too small to allow of a free undulation, so that the lower half of the wave diminishes while the upper half increases, the high water line then inclines upwards, but the low water line still more so, and the range of the tide decreases.

Beyond *C*, the resistance to the passage of the wave has so increased that it cannot maintain its height even at high water, and the high water line begins gradually to incline downwards, so that the range of tide decreases more rapidly than before, and at a certain point (*D*) it will meet the low water line and the tide will vanish.

In some rivers, however, there is still a fourth phase of the tide. If the river channel above *D* be pretty large, a small wave will be propagated along it, and it may even mount many feet above the level of the sea. Thus in the Ganges there is a sensible tide at a distance of 240 miles from the mouth, and at an elevation of 80 feet above the level of the sea. In the Amazon it is felt at a distance of 600 miles and at an elevation of 90 feet. In our small rivers the channels are generally too small for the propagation of a wave upon the land water, and there is seldom an elevation greater than that due to the increased range of the sea wave, but there are cases in which it appears to some extent. In the Tay it is stated that there is a tide, even where the low water of the river is higher than the high water of the sea. In the Severn, at Worcester, there is more rise of tide when the river is raised some feet by land floods than when it is low. When the floods rise still higher the tide again disappears.* When the river is low, the channel

* The tides are by recent works, for the benefit of navigation, shut out at Tewkesbury, 12 miles below Worcester.

is not sufficiently free for the propagation of the wave. When flooded the height is too great.

The points *B*, *C* and *D* are by no means invariable. *B* cannot change much, but *C* will be higher up the river as the tide is higher, and *D* varies not only with the height of the tide but also with that of the land water. A higher tide sends it obviously higher up the river, and a fuller river, as we have just seen, may either assist or impede its advance.

These general principles will give an idea of how the flow of the tide in a river is within the control of art. If the low water channel between *B* and *C* be deepened and widened, the point *B*, where there is the greatest depression of low water, will be brought higher up the river, and facility given for the point *C*, the summit of the high water line, to reach higher up. This of itself will push on the point *D*; while a farther enlargement between *C* and *D* will again facilitate the progress of the wave in this division, and by making the high water line in *C D* more level throw the point at which it meets the low water line, or where the tide ceases, to a greater distance.

In this manner more tide comes into the river, and not only itself assists the navigation of the river, but increases the quantity of water that will flow out and maintain the size of the channels near the mouth.

Another peculiar effect of the river channels upon the tide must be noticed. Bearing in mind that the rate at which the wave travels is dependent upon the depth, and that the depth near low water, or when the wave first enters, is much less than at high water, it will be obvious that the foot of the wave will travel much more slowly than the summit, and that at a certain distance from the mouth the period of flood, *i.e.*, from low water to high water, while the tide is rising, will be much less than the period of ebb, while the water is falling. The tide may take only $4\frac{1}{2}$ hours to rise and 8 hours to fall. Now the effect of this is important. In such a case there is as much tidal water to run up the river in $4\frac{1}{2}$ hours as there is to run down in 8 hours; and therefore, so far as the tidal water is concerned,

the flood current so long as it lasts must be stronger than the ebb. There is, however, to set against this the slope of river bed which affects the energy and the land water current, which increases the ebb and diminishes the flood, and so to a certain extent neutralises the inequality. It does not, however, make a perfect balance. In most rivers, especially in the summer and autumn, when the quantity of land water is small, the flood tide is in certain parts stronger than the ebb, and the effect is that it bears with it certain earthy matters which the ebb tide is not strong enough to carry back, and which are not removed till the floods of winter arrive.

Here is another particular in which art may usefully direct and modify the operations of nature. The larger, deeper, and freer the low water channel, the less will the foot of the wave be retarded in comparison with the head, the longer will the flood tide continue, the less will be the velocity of the current and the more will the powers of the ebb and flood be equalised.

This inequality in the periods of flood and ebb is increased as we go higher up the river by another cause, viz., the inclination of the bed, which prevents the rise from commencing at all till the tide at the river mouth has mounted considerably. Thus in regions to which only the top of the wave can reach flood tide may not last more than an hour; true ebb tide will not last much longer; but the transition from ebb tide to the ordinary river flow will not be detected. Even here, however, there is the same retardation of the flood tide when it first enters the river channel.

In cases where the tide is very large and the channel very shallow, this retardation of the flood tide is productive of a curious phenomenon, called "the bore." The bore is caused when the tidal current necessary for the supply of water is more rapid than the transmission of the foot of the wave. It therefore cannot wait until the channel is tranquilly enlarged by the raising of a wave in it, but the water rises in a foaming head like a great breaker on the seashore.

The most remarkable instance of a bore in this country is in the Severn, about 20 miles below Gloucester.

The high water channel is here nearly a mile wide, but the low water stream is not more than a quarter of that width and from 2 to 3 feet deep; the remaining space is occupied by flat sand banks. The first approach of the tide is indicated by a distant roaring sound, and presently 2 or 3 miles off may be seen a low white line stretching across the river bed. This comes nearer and nearer, till in a few minutes it becomes distinctly visible and audible as a breaking wave 2 or 3 and sometimes 5 or 6 feet high. Where the bottom is shallow it rises higher and moves more slowly; where the water is deeper it moves more rapidly, decreases in height, loses its foaming surface, and becomes simply a gentle swell. Behind the bore follows an impetuous torrent of muddy water, rushing up the river; an instantaneous rise of 3 feet has been effected, and the rise continues rapidly increasing. In 25 minutes from the approach of the bore, the space which had been dry sand is covered with a crowd of vessels, some of 150 tons burden, sailing safely over it, carried along by the current at the rate of 7 or 8 miles an hour. A single sail is set, or a boat with two rowers is towing each vessel, to give her a little motion through the water and the power of steering, but the moving force is the tidal current. In a few minutes 40 or 50 vessels will have passed; they must not be later, or they would "lose their tide"; the current would fail them before they could get into a safe place from the bore of the succeeding tide, which if it caught them in the open river would roll them over and bury them in sand. The tide, however, continues to rise, and in an hour and three-quarters from the passing of the bore it has risen 18 to 20 feet. From this point the river makes a bend in the fore of a horseshoe, and returns after a course of 8 miles to a spot 1½ miles distant from the point at which we have supposed the tide to be first watched. If after the passage of the ships the spectator were to walk over this mile and half, he would find the river again tranquilly flowing towards the

sea. Presently the roaring of the bore will be heard, the banks will be covered, the fleet of coasters will pass on their way (if it be a good tide some of them will "carry it" to Gloucester), in an hour the water will have risen 10 feet and the current will turn. Let the spectator now return to his starting point (Hock Crib), and he will find the river much in the same tranquil state as when he first saw it. The tail of the tide wave alone remains, and the Severn is within the space of 4 hours once more a waste of sand and mud banks.

There is a bore in some other rivers, the Great Ouse, the Parrot and sometimes the Dee, at Chester. In the Hoogly, the Calcutta mouth of the Ganges, it is very strong, and may be heard for many miles. It is also strong in the Amazon. The cause is the same in all, the resistance of the low water channel to the passage of the wave. It is an extreme case of the retardation of the flood tide, and may be avoided by an enlargement of the low water channel, so as to admit the wave more freely.

The Tsien-Tang Kiang River in China is distinguished by a bore which has a cascade 10 to 11 feet high. Special junk shelters are built to enable these vessels to be secured until the river has become normal.

Effect of the Improvement of Tidal Rivers.—Within the last hundred years many very important works have been accomplished for the improvement of tidal rivers, based always upon the principle of facilitating the admission of the tide wave. It may not be uninteresting to notice some of these.

The Thames is probably the most instructive example of all. The artificial works executed upon this river in modern times have been the deepening of the bed below the city, and the removal of old London Bridge.

The effect of the deepening has been that, whereas in 1720 the flood tide commenced only 3 hours 50 minutes before high water, in 1849 the passage of the early flood had been so facilitated that the water at London Bridge began to rise 5 hours 15 minutes before high water. The time of high water

itself has also been accelerated. It now takes place about 2 hours after the moon's transit. In 1683, it was generally reckoned 3 hours after the transit, but in 1213, according to an old time table which is still in existence, the time of high water is given as 3 hours 48 minutes, when the moon was one day old, which would be rather more than 3 hours after the transit, so that in the 470 years previous to 1683 there appears to have been little alteration, while in the 170 years following the high water was accelerated an hour, and the low water at least $2\frac{1}{2}$ hours. Within the last 20 years the change has been still more rapid. In 1833, high water at London Bridge was 1 hour 37 minutes after Sheerness; in 1851, it was only 1 hour 20 minutes, being a gain of 17 minutes in 18 years.

It was during this period that the great changes in the river bed caused by the removal of old London Bridge in 1833 took place.

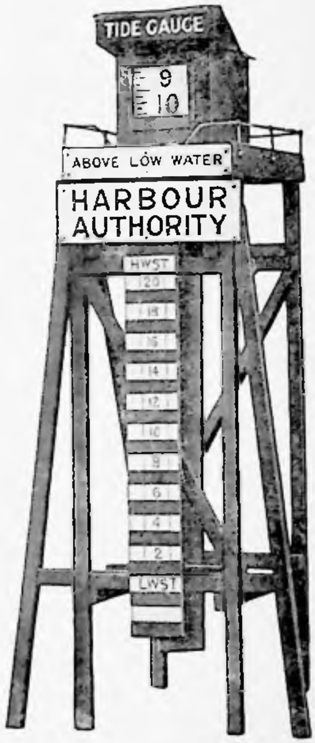
Old London Bridge was more like a huge dam with 19 sluices in it than a bridge, according to our modern notions. At low water it dammed up the river, so that the water surface was 4 to 5 feet higher above bridge than below, and at high water it was 8 inches to a foot higher below than above. The obstruction caused by a new bridge is scarcely perceptible either to the flood or ebb tide.

More recent investigations (1929) shew that the difference of time between H.W. Sheerness and H.W. London Bridge continues to change, the interval now being 1 hour 15 minutes to 1 hour 18 minutes.

Range of Tide and Level of the Ocean.—In the account which we have given, the reader cannot fail to have been struck with the great varieties in the dimensions of the tide wave. We have already explained that the conformation of the shores and bottom will cause some variation, but there are certainly other laws guiding the range of the tide of which we are as yet ignorant.

It has been found by experiment, as we have before stated, that a wave, in travelling along a channel which gradually

contracts in width, becomes higher and higher, and that in emerging from a contracted to a wider channel it diminishes in height. Observation with regard to the tide wave proves that it also is subject to both these laws. In the mouth of almost every river the tide is greater than on the shore of the neighbouring sea. Of the converse law an obvious instance occurs in the Mediterranean, where the tide which was 9 feet high at the Strait of Gibraltar is now approximately 3 feet.



Dolphin Carrying Illuminated Self-acting Tide Gauge.

The meeting of two distinct waves may cause either a combined wave of double height if their summits coincided, or an obliteration of both if the summit of one coincide with the hollow of the other.

These two causes, however, converging channels and

combining waves, are not sufficient to account for many of the great ranges of tide which we find. For instance, the tides of the North-West Coast of Australia and of the Eastern Coast of Patagonia. Each is the scene of the meeting of two tides, but in neither case would the two meeting tides simply mounted one upon the other cause so great a range. In neither case is there any apparent conformation of the land sufficient to account for the increase, but there is evidence of the wave being stationary rather than progressive in one case, and of a very peculiar movement in the other. There is probably some law of undulation not yet clearly understood on which depend these and similar cases

The great rise in the Bristol Channel we might attribute to the bell-mouthed form, but we have a nearly equal rise, and a proportionately greater increase from the mouth to the head, in the Bay of St. Malo, which has a very imperfectly formed bell mouth; while in the numerous estuaries around our coasts a form very similar to that of the Bristol Channel, we find a very obvious increase of range in every case, but generally to a much less extent. Thus the Thames tide increases from 13 feet at the North Foreland to 22 feet at Gravesend; that of the Humber from 19 feet at Grimsby to 21 feet at Hull; that of the Firth of Forth from 14 feet at Fife Ness to 16 feet at Leith; of the Moray Firth from 10 feet at Wick and Banff to 14 feet at Dornoch and Nairn; and in the Shannon the tide gradually increases from 13 feet to 18½ feet. In none of these cases is the increase of range so great as in the Bristol Channel, and the Bay of St. Malo tides are a still stronger case. We may mention, however, two cases of gulf tides which are still more extraordinary and seem to deserve especial investigation, viz., the Bay of Fundy, where the tides increase in range from 13 to 60 feet; and the Adriatic Sea, where they increase from something too small for ordinary observation to from 3 to 5 feet at Venice. In both these cases, however, the information we have been able to find is very meagre. The Gulf of California is remarkable in form, and we might presume

would materially affect the tide. It appears, however, that at Guaymas Harbour* half way up the gulf the rise is only 4 feet, even less than in the open sea at the entrance. Professor Airy states that there is a considerable increase at the head of the gulf,† but does not give his authority. It is not improbable, if this be true, that there is a node near Guaymas. We have remarked upon the evidence of a somewhat similar movement in the Red Sea. On the whole, we may admit that the causes of the most remarkably high tides and increasing ranges is a question yet open to philosophers.

In a river, although, as we have before explained, the actual range of tide decreases above a certain point, yet the proportions of the tide may, and in some cases do, increase. The rise is due, not to a *smaller wave*, but to a *part of a greater* one. The difference is important, because although the difference of level of high water and low water is small, the difference between the high water of a great tide and the high water of a small tide is considerable. Thus at Hock Crib, on the Severn, for instance, where the tide rises 18 feet, it is not a tide wave 18 feet high, but the upper part of a wave from 40 to 50 feet high. The rise and fall are proportionably rapid, and the river remains for several hours in the day without tide at all. At this point neap tides only rise 5 feet, and a few miles higher up they are not felt at all, so that tides only come for a few days at the springs.

This produces a curious anomaly. Where there is a complete tide wave, low water of spring tides is lower than low water of neaps; but in a river where only a part of the wave enters, and neaps are little felt, the low water may be lower at neap tides than at springs, owing to the river channel not having time to pass off the great quantity of tidal water which has been thrown in before the next tide comes. The more perfect the channel, however, the less will this be the case, and in a good state of the river it is probable that, even though the

*Admiralty Chart.

† *Encyclopedia Metropolitana*, article "Tides and Waves."

whole wave may not have access, yet the spring tide, by its greater undulatory force, would draw off the water more than the neap.

A very curious case is found at Ballytaigue Lough, in the county of Wexford. This lough, though of considerable extent, has a very narrow communication with the sea. The effect is, that while *outside* the entrance spring tides rise 11 feet and neaps 6 feet *inside*, springs rise only 2 feet and neaps 3 feet; the low water of spring tides being nearly at the same level as high water at neaps. The quantity of tidal water is limited, not as in an ordinary case by the extent of the lough, but by the capacity of the entrance to pass it. During springs, more runs in than can run out, and the water in the lough is high; during neaps, more runs out than can run in, and the water in the lough is low.

All the observations that have been made on the subject tend to shew that, whatever may be the different ranges of tide at different places, the mean tide level—that is, the point half way between high and low water—is the same at all places on the sea coast, not in rivers; that in fact the tide is an oscillation of the water to an equal height above and below a fixed level. It was found by experiment that the level of half tide in the Bristol Channel, where the range is from 40 to 50 feet, is the same as on the South Coast of Devon, where the range is 13 feet, and a very extended series of observations made under direction of Professor Airy, on the coast of Ireland, prove that there, notwithstanding the great varieties in the range of tide, mean tide level is the same everywhere and at all times.* If there be any variation, it is that in summer the mean tide level is a little lower than in winter.

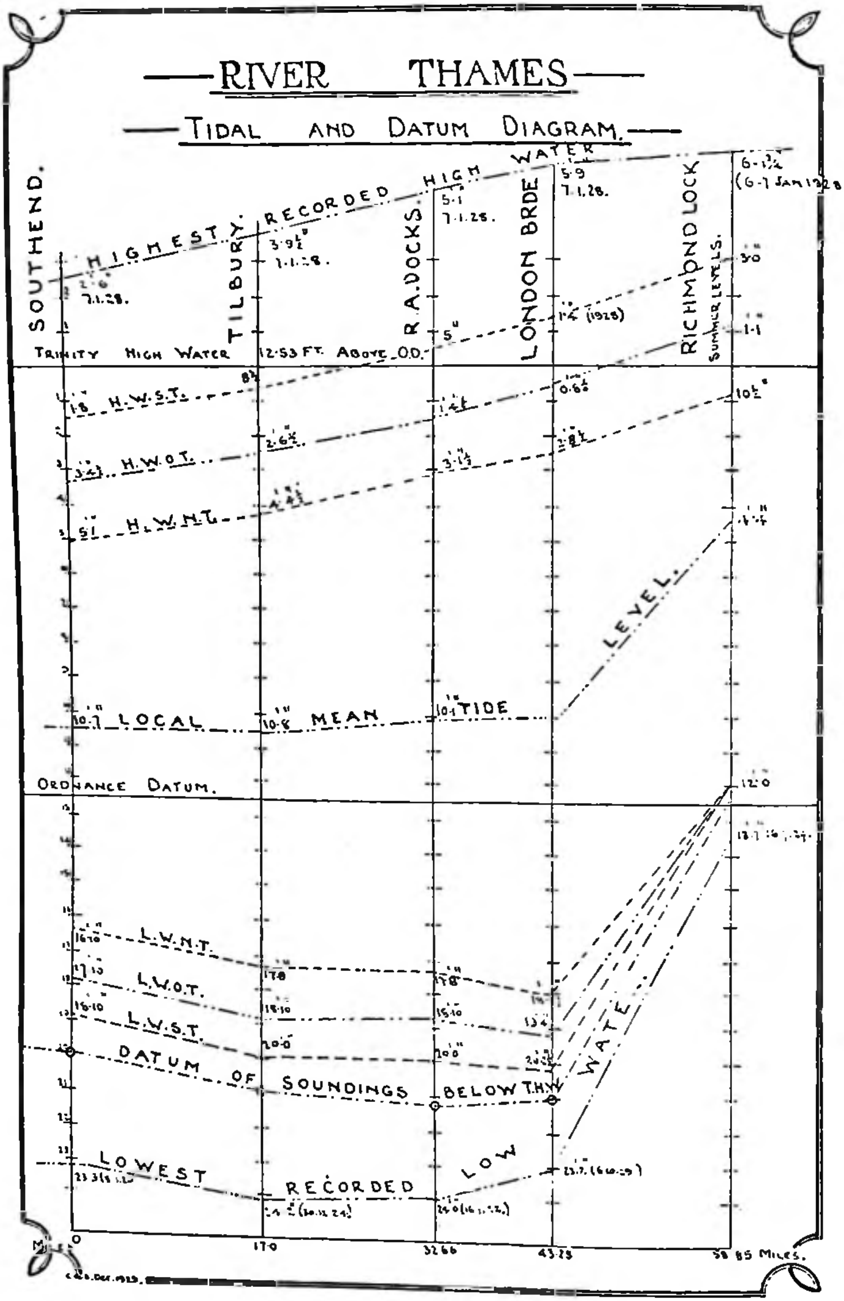
This mean tide level, however, is liable to be changed by meteorological causes, by winds, and the weight of the atmosphere. These causes are often spoken of as affecting *the tide*. This, however, is incorrect, at least in the main; what they affect is the level of *the sea*, high water and low water equally; the *tide* remains the same.

* Recent observations shew a complex condition.

Generally speaking, the wind heaps up the water upon the shore against which it is blowing, and it heaps it up the more according as the width of water over which it has been blowing is greater. South and south-west winds, which blow over the great expanse of the Atlantic, have with us the greatest effect in raising the level of the sea, and if the direction changes at a critical moment from this to a direction which blows upon any particular point of the coast the greatest effects are produced.

The effect of the weight of the atmosphere appears to be pretty regular, but it is difficult to separate it from that of the winds, which are more complicated, especially as the most violent winds generally accompany a very light atmosphere and low barometer. Experiments have been made at London and Liverpool as to the coincidence of the variations of level of the barometer and the sea. From them it appears that a fall of 1 inch of the barometer is accompanied by a rise at Liverpool of 11 inches of the water, and at London of 7 inches. The difference is probably owing to the greater distance of London from the open sea, and the consequently greater difficulty in the escape of the water under pressure. Sir J. C. Ross in 1848 made a series of experiments in the Arctic regions under circumstances very favourable to the determination of this question, being in a locality where the tide was little affected, either by the agitation of the sea or by local winds, and he found that a rise of 1 inch of the barometer was accompanied by a depression of the sea of $13\frac{1}{2}$ inches. Now it is curious that if a barometer were made with sea water instead of mercury it would rise and fall about $13\frac{1}{2}$ inches for every inch of the mercurial barometer from which it would seem that the open sea is a great natural barometer, indicating the weight of the air. The sea and the atmosphere, both fluids, so arrange themselves as to equalise the total pressure upon the earth, when one is lighter the other is heavier.

Many of our ports being situated upon rivers, a third cause of disturbance of mean tide level becomes important, namely,



RIVER THAMES
TIDAL AND DATUM DIAGRAM.
SOUTHEND.
TILBURY.
R.A.DOCKS.
LONDON BRDE.
RICHMOND LOCK.
SUMMER LEVELS.
HIGHEST RECORDED HIGH WATER
TRINITY HIGH WATER 12·53 FT. ABOVE O.D.
H.W.S.T.
H.W.O.T.
H.W.N.T.
LOCAL MEAN TIDE LEVEL.
ORDNANCE DATUM.
L.W.N.T.
L.W.O.T.
L.W.S.T.
DATUM OF SOUNDINGS BELOW T.H.W.
LOWEST RECORDED LOW WATER
MILES 0
17·0
32·66
43·23
58·85 MILES.

freshets or land floods. These are generally imperceptible at the mouth of a river, but higher up they sometimes raise the surface of the water as much as 20 feet. Under favourable circumstances, and to a certain extent, as we have seen in the case of the Severn, they assist the tidal flow, but in greater force they overpower it. In all cases in a river they raise the level of both high and low water, but the latter more than the former, so that the range of tide is diminished. They are a very valuable agent in scouring out the bed of a navigable river where the tide does not reach in great force. In fact, the navigation of a tidal river may be said to depend upon these two agents, the land floods great above, and gradually diminishing in descending; and the tides great below, and gradually diminishing in ascending.

CHAPTER IV.

THE MEASUREMENTS OF A SHIP—BORINGS—THE DREDGER AND EFFECT OF TYPE ON ECONOMICS—DISPOSAL OF MATERIAL—TOP TUMBLERS OF BUCKET DREDGERS, WEAR, TEAR AND TYPES—SPECIFICATION NOTES—DRAGS AND ERODERS IN ACTUAL PRACTICE—LOGS, BOOKS AND JOURNALS.

The Measurements of a Ship.—Dredging vessels do not always conform to the definition of a ship unless of seagoing type, when their form requires study and their construction of hull is, apart from the dredging appliances and ladder-well, of seagoing ship type. We therefore offer no apologies for presenting a graphic record of the official measurements of a ship under British Board of Trade and Lloyd's Registry Rules.

The International Rules for guidance of mariners in preventing collisions at sea state that the "length of a ship shall be deemed to be that given in the Certificate of Registry."

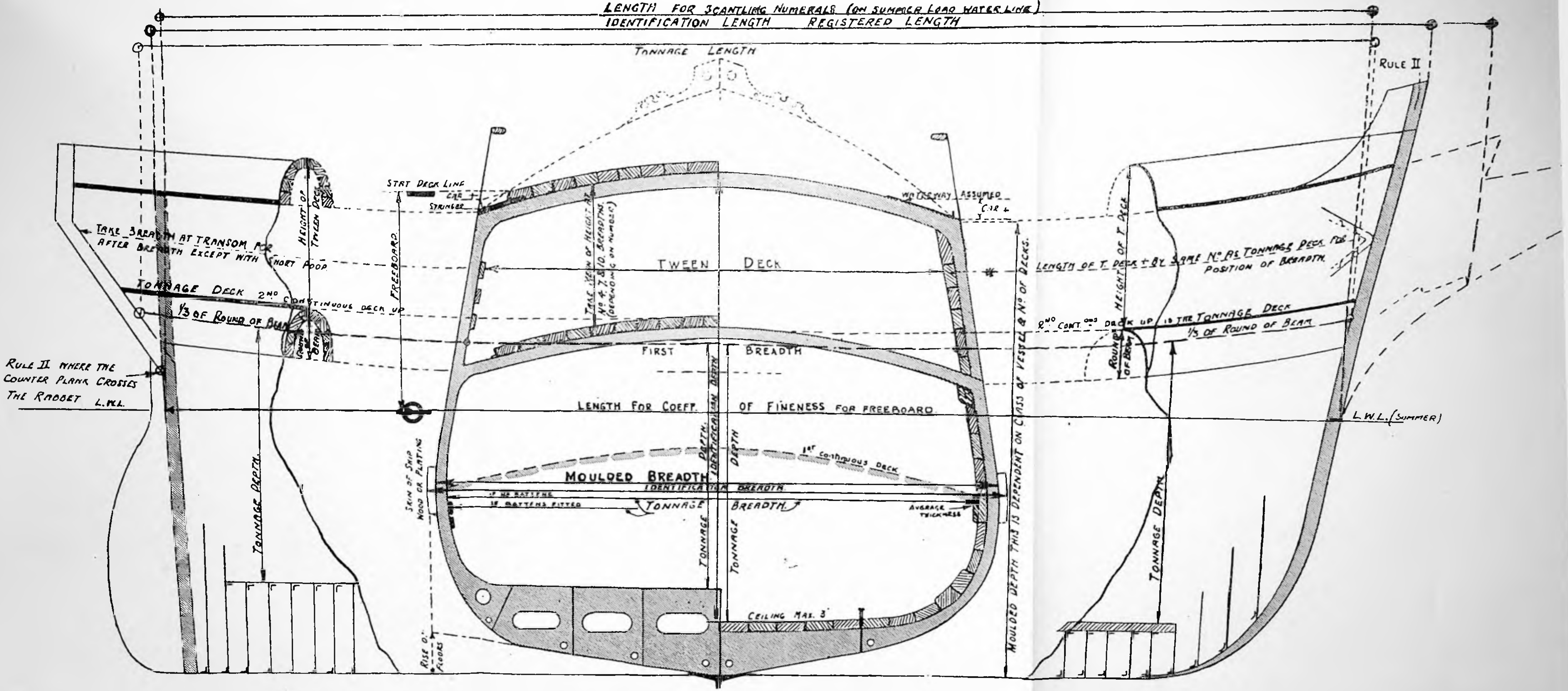
There are variants of length in the dimensions of a ship which should be understood.

Length between perpendiculars.
Length overall, etc.

Also in breadth of a ship, wooden fenders of a longitudinal character are outside of the moulded breadth; such fenders are usually fitted to dredging vessels.

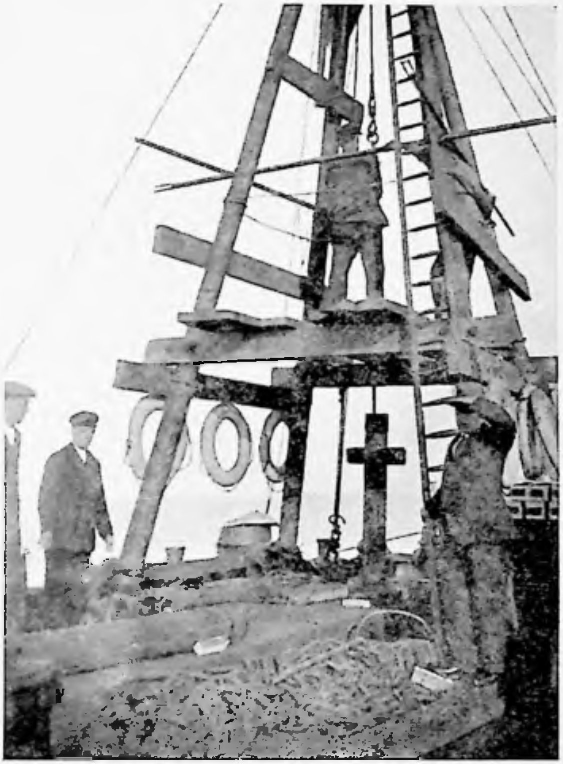
In other respects the plan is self-explanatory.

Borings.—Borings taken as a precautionary measure to determine the nature of ground before dredging is now more common than heretofore. The information thus obtained may actually decide the type of plant to be employed on a particular dredging undertaking, and all uncertainty thus removed.



To face page 108.

We have known of a dredging scheme where the strata proved from borings so variable that the plant was consequently designed beforehand for alternative treatment by bucket dredger and/or suction in the same vessel. There have been cases in which the plant built for work proved unsuitable owing to



Trial Boring Operations for the Port of London Authority, Thames Estuary (10 miles off Margate). Le Grand, Sutcliff & Gell, Ltd., June, 1925.

the superficial and defective nature of the investigations which preceded the estimate of material, in character and in stratification.

Borings may be taken from a hopper at anchor or moored by erecting the stage over the well, the hopper doors having been opened for the occasion.

In smooth water a raft is usually employed with suitable apparatus to prevent the raft slewing during the process of boring. Six anchors and cables are frequently employed. When the crust has been broken by the boring tool it sometimes occurs that the boring tube requires checking, its descent being so fast.

6-inch Diameter Trial Borings in operation at Low Tide in the River Crouch, Creeksea, Essex. Le Grand, Sutcliff & Gell, Ltd., London, 1928.

The time taken to each boring usually depends on the depth it is desired to draw the sample from; but this is not an invariable rule.

Bore holes are put down by one or other of the following methods (Kempfe):

(1) Percussive (*a*) Using solid rigid rods.
(*b*) Using ropes.
(*c*) Using hollow rods (waterflush method).
(*d*) Using a hydraulic ram.

(2) Rotary (*A*) core drills.
(*a*) Using diamonds.
(*b*) Using steel cutting teeth.
(*c*) Using chilled shot.
(*B*) Hydraulic rotary oil drill.

Generally speaking, percussive methods are used when the primary object is to get a hole down rapidly. In such a method

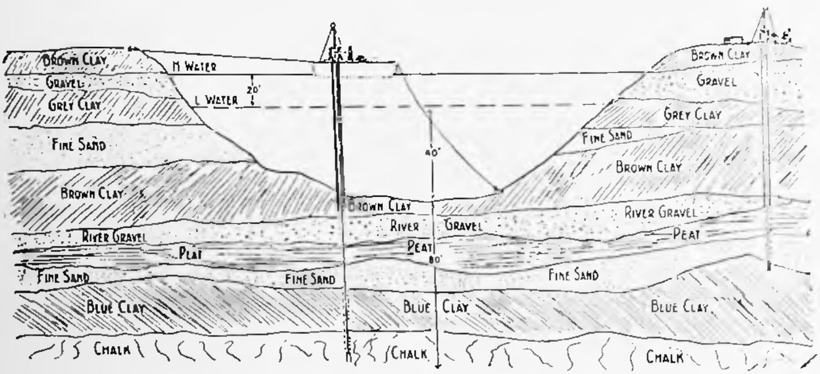
Making Trial Boreholes in the Sea to test for Foundations in connection with the proposed New Harbour Works at Haifa, Palestine, January, 1928.
Consulting Engineers, Messrs. Rendell, Palmer & Tritton.
Rig and Foreman Driller supplied by Messrs. Le Grand, Sutcliff & Gell, Ltd., Southall, London.

the nature of the ground passed through is of less importance. whereas for dredging information the nature of the ground from the surface level to the possible extreme of dredging is of first importance. Rotary core drills are therefore preferred for dredging data as a more or less continuous core is obtained providing accurate information. In operating the percussion method the strata are pounded into a paste or cut up into irregular pieces by the percussion action of the chisels and the debris removed by means of a shell, or bailer, which is a steel pod fitted with a valve at its lower extremity. Where it is found necessary, steel tubing of the required diameter is inserted in the bore hole to prevent the sides from collapsing.

Costs.—A complete drilling rig for making 6-inch holes would cost (1930) about £120, excluding the cost of the necessary steel lining tubes. Cost of boring operations vary from 10s.-15s. a foot on land and from 25s. to £5 a foot from raft or lighters afloat.

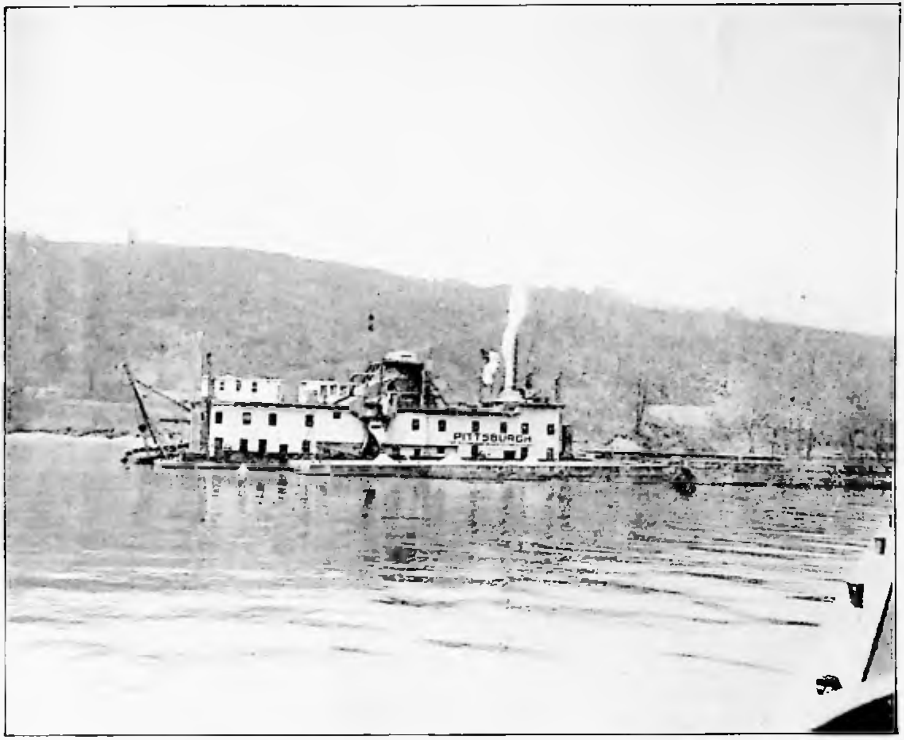
Types and Economics of Dredgers.

In discussing the economics and hydrography of dredging operations it is necessary to differentiate between types of plant if only for the purpose of considering costs. The cost per cubic yard for dredging varies much with depth of water and other considerations, *e.g.*, the quantity to be removed,

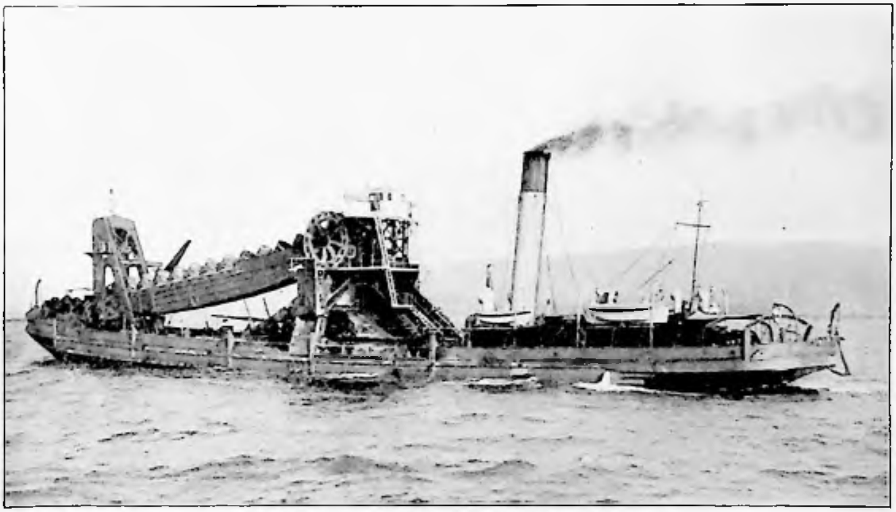


Sketch to Illustrate Method of making Trial Boreholes in River and on Land.

character of material (which may require occasional blasting), the distance to which it has to be removed, whether it can be at once discharged by means of projecting side shoots or slides, or must be discharged into hoppers, scows or lighters, whether the removal may be effected by poling a short distance, or by a greater by steam or motor tugs, whether it can be dropped or dumped into deep water by means of flap or trap doors in the bottom of the conveying craft, or must be shovelled out by hand from lighters—a method obviously for small operations and useful in reparation of embankments—whether much time must be consumed in



Ohio River Dredger operating a Close-linked Bucket Chain.
Dredger is fitted to grade and separate dredgings before discharge into barges.



Twin-Screw Sea-going Hopper Bucket Dredger *David Dale*.
Built for L.N.E.R. Coy. by Lobnitz & Co.

moving the dredger forward frequently as when the cut is narrow or material scattered, or in working at little depth, exposure and weather.

These considerations may make the cost per cubic yard in one case two to four times as great as in another. Cost may include all repairs but no profit, and *vice versa*.

It is evident that the subject admits of no great precision. Small jobs, even in favourable material but in inconvenient positions, may readily cost two or three times more than deeper dredging, although in deep dredging generally costs are greater owing to the greater height the dredgings have to be lifted. Neither do the buckets become so well filled in deep dredging as the arc the bucket chain covers takes a steeper angle of excavation than in shallow water.

Functions differing with type it is desirable to make clear the functions of each. In the case of the stationary or non-seagoing bucket dredger a hopper fleet is necessary. These hoppers may be open barges towed by tugs or self-propelled hoppers. The material to be dredged is raised by means of a continuous chain of moving buckets kept in position by the ladder of the dredger, which can be moved up and down as tide falls and rises and/or as excavation proceeds. The bucket chain engages in a rotor usually of 4 facets keyed to the rotary shaft at upper end of ladder. This rotor is termed the top "tumbler" and is rotated by bevel or belt drive from an engine actuated by steam or other prime mover. The buckets at the upper end of the radius discharge into a shoot which diverts the dredgings overside if discharging into attendant hopper, or into the hopper well of the dredger if of the seagoing type.

To maintain position in the channel the dredger is equipped with moorings, the bucket dredger requiring as a general rule six—one ahead, one astern, one on each bow, and one on each quarter. In working the seagoing dredger the moorings may be allowed to lie in the channel to be picked up on resumption of dredging, or laid out afresh on each occasion. It is sometimes necessary for the dredger to slack down moorings and

draw to one side in order to accommodate passing traffic. The trailing suction dredger does not moor but steams about in the channel, simultaneously pumping the material into the hold or well of the vessel.

Any and all of the aboves types may be equipped with grabs to function as grab dredgers when required.

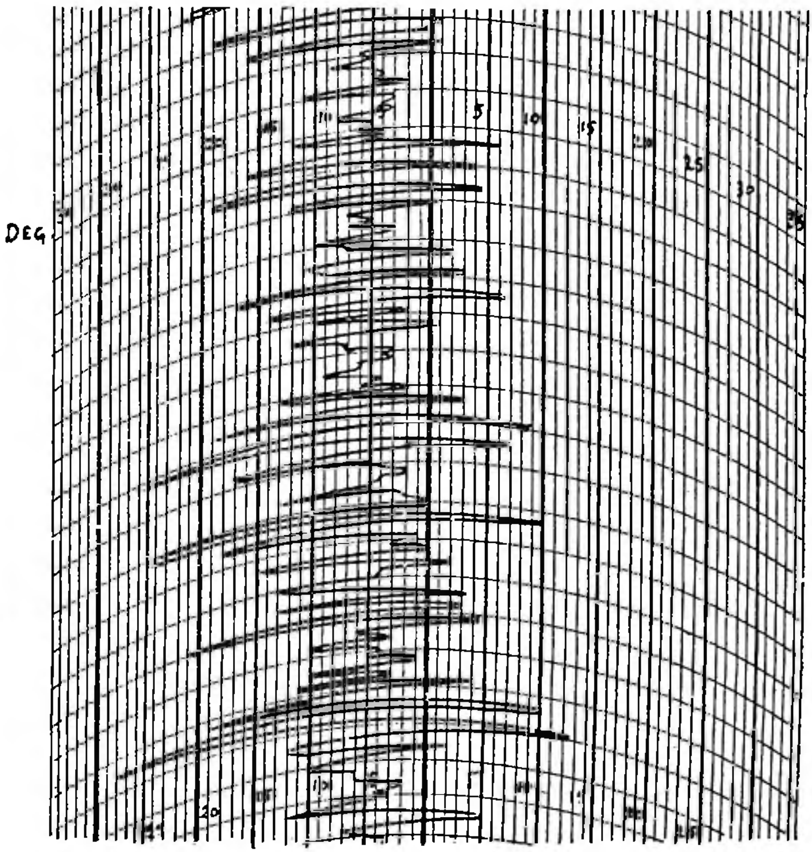
In the operation of a trailing suction dredger a powerful centrifugal pump draws the materials through a specially designed mouthpiece up the suction pipe and discharges them into the hopper well of the dredger, the water being allowed to escape overboard. The materials to be dredged when of a stiff nature are loosened by powerful hydraulic jets placed near the mouth of the suction pipe. When in use the dredger is not moored but is propelled over the area to be dredged usually by twin screws. As soon as the vessel reaches the area to be dredged the suction pipe is lowered, the speed reduced and the vessel moves continuously over the area sucking up sand until the hopper well is full; after which the suction pipe is raised and the dredger proceeds to deposit the dredgings at sea. After emptying the hopper well the dredger returns to the area to be dredged and resumes dredging operations.

The absence of moorings reduces the time lost in taking up position as described in the operations of the hopper bucket dredger (self-propelled).

The suction dredger is able to dredge loose materials such as sand, silt, stones; but is unable to dredge hard materials such as boulder clay and indurated gravel. The speed of raising of the suction dredger is, however, much greater in suitable material than the speed of the bucket dredger.

Having had experience in the effect of dredging by the stationary suction dredger of the non-trailing type, it may be truly said that for maintenance of channels—with suitable material—they are the greatest dredging advance of modern times. When the current is swift as in the Mersey channels it is necessary to anchor the suction dredger, shearing the vessel about easily in order to search the ground well.

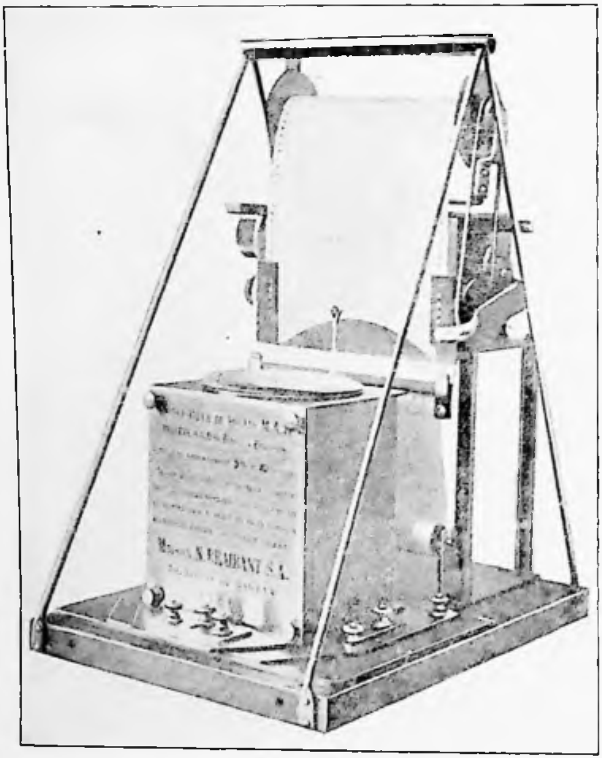
When heavy weather sets in, or a ground swell occurs, there is possibility of the pump suctions being damaged. It is essentially a matter of judgment to determine the moment that dredging should be discontinued. Rolling indicators are



now available which show graphically the extent of the "heave" in a vessel operating in exposed waters. By these records which are registered by a continuation of dock and pendulum or the barograph principle, a diagrammatic result is obtained shewing the conditions which caused a cessation of dredging.

Deposit of Dredgings on Land.—Among the several methods

for the deposit of dredgings, the system usually employed in the dredging of canals, such as Panama, Suez and Manchester Ship Canal is to pump the spoil on to land specially prepared beforehand with retaining walls or embankments. By this system the material is raised either by bucket dredger or by suction, probably using a cutter device at the nozzle to break up



Rolling Indicator.

the surface or crust. The dredgings are either previously loaded into a specially designed hopper which when full proceeds to the pump site, or the dredger itself fitted with overhead shute for passing the dredgings on to the land after being raised, the vessel meanwhile traversing the dredging area while pumping into the delivery. We visited a site on the Swale (Kent) under reclamation in 1924 and took the following notes:

Area under reclamation approx. $\frac{1}{2}$ mile $\times \frac{1}{4}$ mile previously liable to tidal floods; and lying about 10 feet below level of H.W.O.S.T.

The area was specially embanked in form of a reservoir to prevent overflow of water to adjacent lands, and to retain the spoil.

Approximately 20 per cent. of the dredged material became run off owing to the moisture content, *i.e.*, 80 per cent. of the material raised became retained. For the continuous elimination of the moisture content, sluices were fitted at suitable situations.

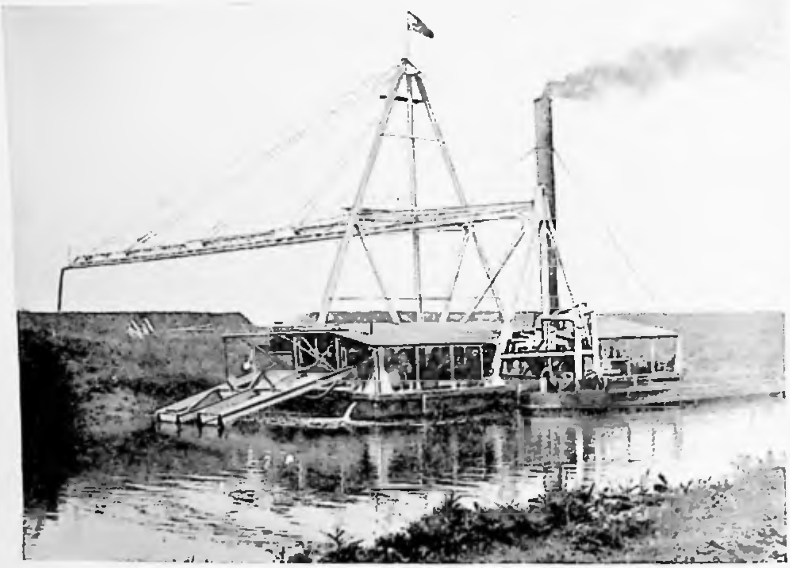
The delivery pipes were branched at the spoil site to permit of discharge in two areas, so that when one area was receiving the dredgings the other area would be settling and drying out. This alternative delivery also serves to divert dredgings as they change in material to selected situations on the site, a longer branch carrying rubble and stones to a different situation than the branch carrying clay and silt.

We have witnessed a mixed barge load of mud, bricks, stones and debris being pumped from the barge on to the deposit site. This was effected by having a suction of 24 in. in diameter of considerable centrifugal force, the nozzle of which is moved about inside the barge load in a similar manner to the nozzle of a grain elevator suction pipe, the indraught being sufficient to raise four bricks cemented together. A supply of water greater than that which the suction pump is capable of delivering in liquid dredgings is required to flood the suction area in the hopper barge during pumping. This is arranged for by the pump vessel having separate pumps—one to flood, the other to raise, the material so immersed from the barge.

When the operations are likely to fix the place of pumping for some time a pump station may be rigged on the jetty, otherwise the pumping vessel lies alongside the jetty. It is essential for the efficiency of the work that there will be no shortage of water and no tidal limitations. The discharge piping is usually built up and carried on trestles which provide

a gradient or fall throughout the distance from pump to outlet on site.

In considering costs, the area of land available for the particular job, the period required to fill the area, cost of land before and after filling or reclamation require primary consideration.



For Canal or River Work Lobnitz Dredgers have a Record of Achievement.

In the Manchester Ship Canal the excavations were piled to a considerable height to overcome the limited area which they had at their disposal. The plant and methods employed are given in the following report (*q.v.*), supplied by the Engineering Department of the Canal, to whom I am indebted for the information.

Manchester Ship Canal.

Notes on the Deposit of Dredgings Ashore by Pumping.—There are considerable areas of low-lying land adjacent to the Canal, including the old beds of streams diverted to the purposes

of the Canal, which are being gradually filled up and raised. These make excellent tipping grounds and the Company has generally three in active use.

A depositing unit consists of:—

(1) 2 "Gwynne" invincible centrifugal direct acting steam pumps, 15-inch dia. for pumping and discharging the silt.

2 9-inch direct acting centrifugal pumps for diluting the heavier part of the silt so that it may be pumped.

2 multitubular boilers of the semi-portable type, the necessary winches, suction pipes, etc.

This plant is erected and suitably housed on a jetty adjacent to the land it is intended to fill up. The flexible pipes from the suction and diluting pumps depend from supports in front of the jetty, whilst the discharge pipes at the rear convey the silt to the ground, from whence it flows by gravitation over the whole area.

As soon as the barge comes alongside the four pipes are lowered into it and pumping commences; the time occupied in emptying an 800-yard barge being between *one and two hours* varying according to the gravity of the material but averaging $1\frac{1}{2}$ hours.

The Company has two plants of this description which at the present time together dispose of nearly one million cubic yards per annum.

(2) The Company in 1912 constructed a floating pumping plant which is being used on the tidal portion of the Canal, where there is a difference of level amounting to 5 feet at spring tides.

The plant consists of a reinforced concrete pontoon, 100 feet long, 29 feet beam, 8 ft. 6 ins. deep, carrying:—

(1) 18-inch direct acting "Gwynne" centrifugal pump and surface condensing engine.

(2) 12-inch diluting pumps.

(3) Marine type multibular boiler and the necessary suction and delivery pipes.

The advantage of this plant is its portability and the greater efficiency of the larger pump with a short suction. It can be moved from place to place as required, and is expected to be most useful in filling up sites where the ordinary pumping plant would be impracticable.

Previous to the deposit of the dredgings, a bank is formed around the area to be filled up. This varies in height according to the depth of the proposed deposit. Where the area is extensive it is generally necessary to form cross banks. This enables the work to go on in one section whilst the deposit in the other is consolidating and drying. The banks are then raised from the dried material.

The present (1923) cost of pumping is as follows:—

Tidal division (No. 2 floating plant)—

Average quantity per month 50,820; wages 1·24; coal and stores 0·40; repairs 0·16; charge to cover cost of plant and banks 1·00; total 2·80 pence.

Non-tidal (No. 1 plant)—

Average quantity per month 80·300; wages 1·37; coal and stores 0·51; repairs 0·44; charge to cover cost of plant and banks 0·50; total 2·82 pence.

Pre-war cost of depositing plant and banks—No. (1) £5200; deposit ground disposed of 3,200,000 cub. yards. No. (2) £12,200; deposit ground disposed of 4,500,000 cub. yards.

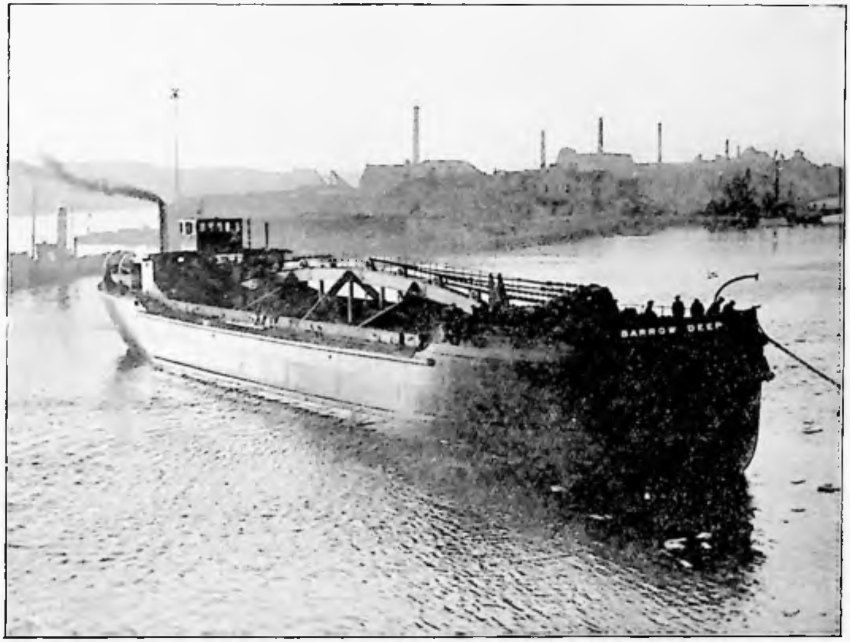
Plant is in each case available for further work.

Removal of No. 2 to Saltport and new banks (post-war) £14,300; capacity of ground 3,800,000 cub. yds.

During the excavation for the Tilbury Dock improvements in 1927-28-29 approx. one and a half million cubic yards *in situ* were removed by bucket dredger and carried in hopper barges to a reclamation site outside the dock area where the material was disposed of. The following notes give the detail of disposal at the reclamation site.

Reclamation Work at East Tilbury.—

1. Acreage of approximately 78 acres was enclosed by an embankment at a similar level to the main river bank.



By permission of Tilbury Dredging Company.

Type of Hopper Barge used in Port of London.

This embankment being formed by a "Ruston" excavator, the main portion of the embankment was approximately 12 feet high and 20 feet thick at base, and about 6 to 8 feet at the top.

2. The plant engaged on the work of dredging in addition to the Ruston mentioned above was as follows:—

(*a*) A 600-litre (21 cub. ft.) bucket dredger belt driven of the usual Dutch type, non-propelling in dock.

By courtesy of Kalis & Co.

Tilbury. Dredging Slopes behind Piers.

This dredger was occupied lifting the material from the dredging site and loading into transporter barges for conveyance to the deposit site. Dredger tipping 14 buckets per minute and loaded 250 cub. yds. in 24 minutes, or at the rate of 626 cub. yds. per hour, at time of inspection.

The material, soft and of a free dredging nature. When working in the sticky clay 40 minutes were sometimes necessary to load the 250 cub. yds. or at the rate of 375 cub. yds. per hour. This would be

accounted for by the material not delivering freely and being heavier pulling by dredger. Buckets had to be regularly dug out when working in clay.

(*b*) Four 250 yd. transporter barges and two converted 250 cub. yd. hoppers, the doors of the latter having been closed and runners placed longitudinally for suction head of reclaiming dredger to operate on. These 6 barges were the carrying mediums between the dredger and the deposit site.

(*c*) Three tugs engaged towing between the dredger and deposit site.

(*d*) A pontoon pump vessel utilised for pumping the material from barge to site.

This machine was fitted with two independent pump engines, the main or spoil pump being triple expansion engine developing 450 i.h.p. when running at 160 revs. per min. The suction and delivery pipes are both of 24-inch diameter. The pump was of the ordinary centrifugal open impeller Dutch type, fitted with the usual stone box, renewable liners being fitted in the pump of manganese steel plates 1 inch in thickness.

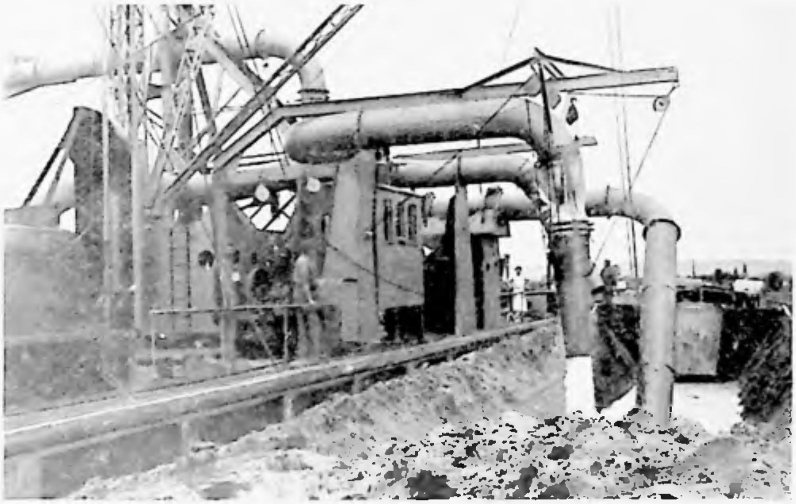
The water pump was also triple expansion and developed 250 i.h.p. at 220 revs. per min. The control of water was from the deck and operated by the master of the dredger, the quantity necessary to cause easy flow varying with the nature of the material and the distance pumped.

(*e*) Motor launch in attendance on supervisory staff and towing barges in dock when not required on supervision.

3. The rate of disposal varied considerably, so many contingencies occurring to cause fluctuation such as varying nature of material being dredged, undocking and docking of hoppers at Tilbury lock, high or low water at pump, etc. An

average week's work was about 120 barges or approximately 30,000 cub. yds.; the best week's work being 130 barges or approximately 32,500 cub. yds.

The pumping time when discharging 250 cub. yds. varied from 20 mins. to as much as 38 mins., the longer time being at low water when the lift is considerably greater than at high water. The nature of the material also affects the pumping time to a considerable degree.



By courtesy of Kalis & Co.

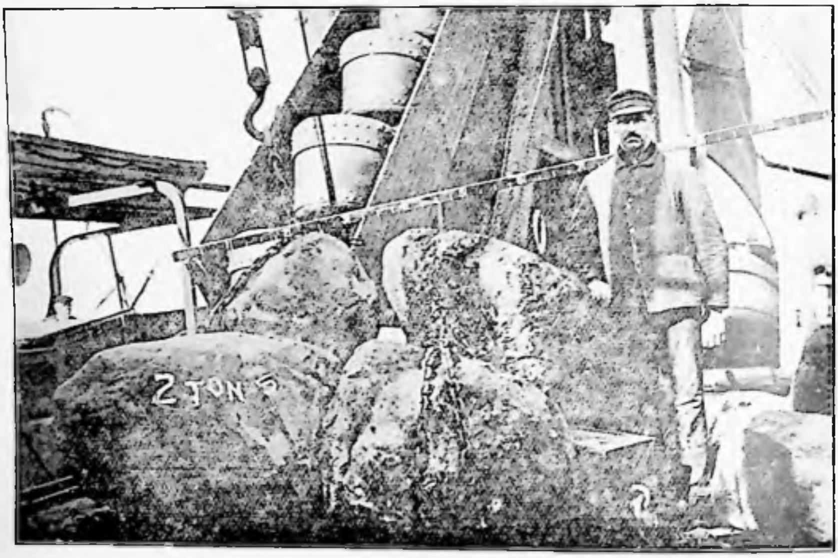
Reclaiming with Dredgings from Tilbury Dock Extension, 1929.

4. The material was pumped through one main pump line, branching at about 450 feet from the pump. One branch running westward almost parallel with the river bank, the other running northward towards the inshore end of the deposit area. The pipe lines were extended as the area filled to bank level. Each discharge utilised alternately, allowing settlement to take place at each outlet and for the extension of the idle pump line without interruption of the work.

The effluent was run off over two spillways situated widely apart, draining different portions of the area as the material settled. These spillways were ordinary open weirs constructed

of timber about 4 ft. 0 ins. in width, the height being regulated as required by the addition or removal of 9-inch high deals.

The connection between pump and shore was made by universal joint and telescopic length of pipe, the moving portion of the telescope being carried on light bogeys for free movement. The discharge pipes were of various construction so far as plating was concerned, but all were of $\frac{1}{4}$-inch material, the newest type being made in two half sections rolled and riveted longitudinally with two seams of rivets, one on either side.



Concrete dredged from Halfway Reach, River Thames.

They were riveted, in addition at the ends to the coupling flanges, but no intermediate butts introduced. This appeared to be an economical type of delivery pipe.

The coal consumption of the pump when running at top speed was approximately 7 cwts. per hour. This appears somewhat low and might average actually somewhat higher.

Performance in Variable Strata.

The bucket dredgers of the 27 cub. ft. type employed by the Port Authority were, and are, capable of dealing with

conglomerate, chalk, septaria, greensand, stiff clay in addition to alluvium, sand or commercial silt. The bucket dredgers of lesser capacity were also capable of breaking up and raising rock formations of the conglomerate type.

Some performances are shewn on following table:—

OUTPUT OF PORT OF LONDON AUTHORITY'S DREDGERS.

Output over one day working 24 hours. Includes stoppages and getting hoppers alongside.

Dredger	Bucket capacity cub. ft.	Material in cub. yds.				
		Silt	Chalk	Hard sand	Ballast	Clay
Nos. 6 and 7*	27	7,500	4,500	2,250	7,000	2,500
India	15	4,500	2,700	1,200	2,950	1,650
No. 10 (see note)†	14	—	—	—	4,000	—
Nos. 4 and 5	10	4,000	2,600	1,125	2,750	1,600
Tilbury	7	2,800	Nil	Nil	2,100	Nil
Grab No. 14 3 cranes	65 (heaped)	500‡	—	—	—	—

*Averaging 40,000 cub. yds. per working week under favourable conditions.

† Dredger No. 10 specifically built for dealing with areas at great depth has done 500 tons per hour during acceptance trials working at 70 feet—W. Level.

‡ Includes time occupied in running to and from spoil ground for dumping load and for straightforward working with no delays.

The number of buckets in use in a bucket chain varies with circumstances. When dredging deep—with the ladder at its maximum depth—the bucket ladder does not require to be so taut as when operating in shallower water. Normally the number of buckets in use in the P.L.A. dredgers were:

Dredger No. 7=27 cubic feet buckets=42 (dredging to 55 ft.)
No. 4=10 ,, ,, =48 (dredging to 65 ft.)
No. 10=14 ,, ,, =45 (dredging to 70 ft.)

For the ten years ended 1st April, 1928, the cube yardage of silt, alluvium and drift removed from the river totalled as follows:—

	Cub. yds.
(1) Above London Bridge	128,626
(2) London Bridge to King George V. Dock	2,092,442
(3) King George V. Dock to Tilbury ..	12,984,600
(4) Tilbury to Seaward Limit	4,942,322
(5) (In River) Dock Entrances	5,104,969
	25,252,959

Other Ports.—The bucket dredgers employed by the British Admiralty at Rosyth were mostly of 1 cubic yard (27 cubic ft.) capacity.

Transmission or Drive.—The transmission of motion from dredging engines to top tumbler may be either by gearing furnished with a friction device or by two belts on a pulley shaft, the latter carrying two steel pinions which drive the spur wheels mounted on the tumbler shaft. In Holland the belt transmission is generally preferred, and especially for soft maintenance dredging it is a more economical form of drive.

The belt slip which occurs where abnormal strains are set up acts as a relief to the bucket chain. Conversely when heavy excavation is unavoidable, the friction wheel and vertical shaft drive being invaluable. The ratio of reduction of the transmission is about 20 to 1, so that at 120 revolutions of the engine the pentagonal tumbler revolves six times, which amounts to 15 buckets a minute, under normal conditions of working.

Grab Dredging.—For dredging in situations where a large output is required, grab dredging is not the most desirable method, but it may be necessary to employ it for other reasons. Hole and corner work can best be done by a grab dredger.

These dredgers may be self-propelled and carry the spoil away or load it into barges which are towed away to the deposit site.

During the past twenty years, the improvement in grabs has been remarkable. This development is owing to the large field of experimentation opened up for the dealing of bulk cargoes of manganese or copper ore, coal and other commodities. Consequently the manufacturers have also improved on grabs for harbour dredgers.

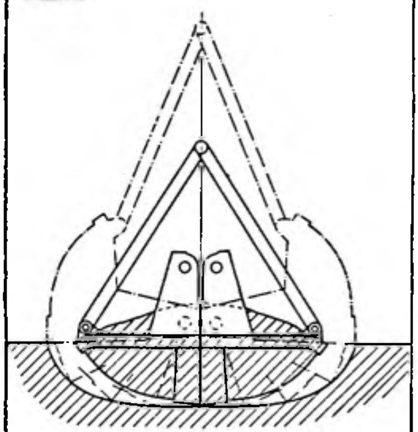
The calculation of digging pressures for a wide range of working conditions has produced definite information which can be studied beforehand, thus enabling a selection of grab to be made.

Digging pressures for clay or greensand are vastly greater

to effect excavation than in the case of mud. The shape, proportions and mounting of the grab jaws require special attention, with the result that the amount of material lifted for a given weight of grab may be raised to the maximum.

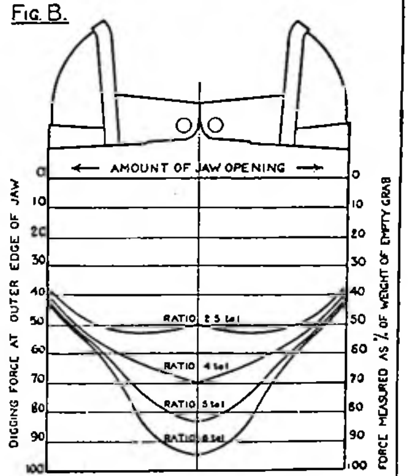
Fig. *A* shews how the grab jaws close in the material and allow ample clearance in the act, thus avoiding useless digging resistance.

FIG. A.



APPROXIMATE SHAPE OF CUT BY A PRIESTMAN GRAB IN LOOSE SAND.

FIG. B.



CALCULATED DIGGING PRESSURES WITH DIFFERENT CLOSING PURCHASE RATIOS.

Fig. *B* shows the comparative of varying the purchase ratio of the closing gear with an empty grab. The weight of material in the grab causes a corresponding increase in the digging pressures, which reach their maximum value as the grab closes, forcing the jaws together and crushing any obstruction.

Excessive multiplation of sheaves in order to increase the purchase and to obtain a high nominal closing power introduces, however, unnecessary friction with decreased efficiency and increased wear on the closing rope of the chain.

In practice, other factors also affect the final design of any particular class of grab, and the important consideration is that the closing gear should be of correct design for the material in which the grab is to work.

The wide range of design is shown on the illustrations on pages 129, 130 and 131.

Grab Dredger and Wreck Raising Vessels.—Among the diverse appliances used in harbour dredging that of the grab dredger, built and fitted for wreck raising operations, is one of the most useful of vessels. When used for dredging the material is loaded into a towed hopper or into another river vessel such as a steam float or barge.

The grab has proved useful in salvage operations especially with vessels having bulk cargoes of coal which have been sunk or beached after collision. Their appliances in detail are enumerated in the following paragraphs.

The grab as a labour-saving device is familiar to all who frequent industrial centres or where the transport of minerals or cargo is carried on. On many railway systems and in many harbours coal, ores, sand, gravel, seeds and grain are loaded and discharged by this means.

Dredging Mud and Dock Garbage.—The particular purpose for which the grab stands far ahead of any other appliance is that of maintaining docks, harbours, and rivers free from silt. Silt is taken to mean not only mud which has settled there, but garbage of every description which has been thrown or accidentally fallen in. This latter may consist of contributions from vessels' cargoes and refuse from dock quays. Amongst the various articles picked up are coal, ashes, pieces of hemp and wire, mooring ropes and rigging, barrels, cement, nails, bales, railway metals, bundles of bar and hoop iron, pigs of lead, copper and iron, logs of hardwood, cargo trucks, etc.

The grab deals with all these without injury to itself or appreciable delay to the work on which it is engaged. The greater part of the silt is due to the accumulation of solids which are brought up in suspension by the tide, particularly

in stormy weather, and which are carried into the docks either by flow or by pumping. This latter operation is necessary in order to keep the locks to their working level, the loss of water which is required to be made good being due to leakage,

Grab Bucket for Mud.

to locking of vessels in and out, and to the failure of tides to reach the normal working level. The solid matter thus carried into the docks is precipitated to the bottom after the gates are shut.

The grab method of dredging has been in use for a number

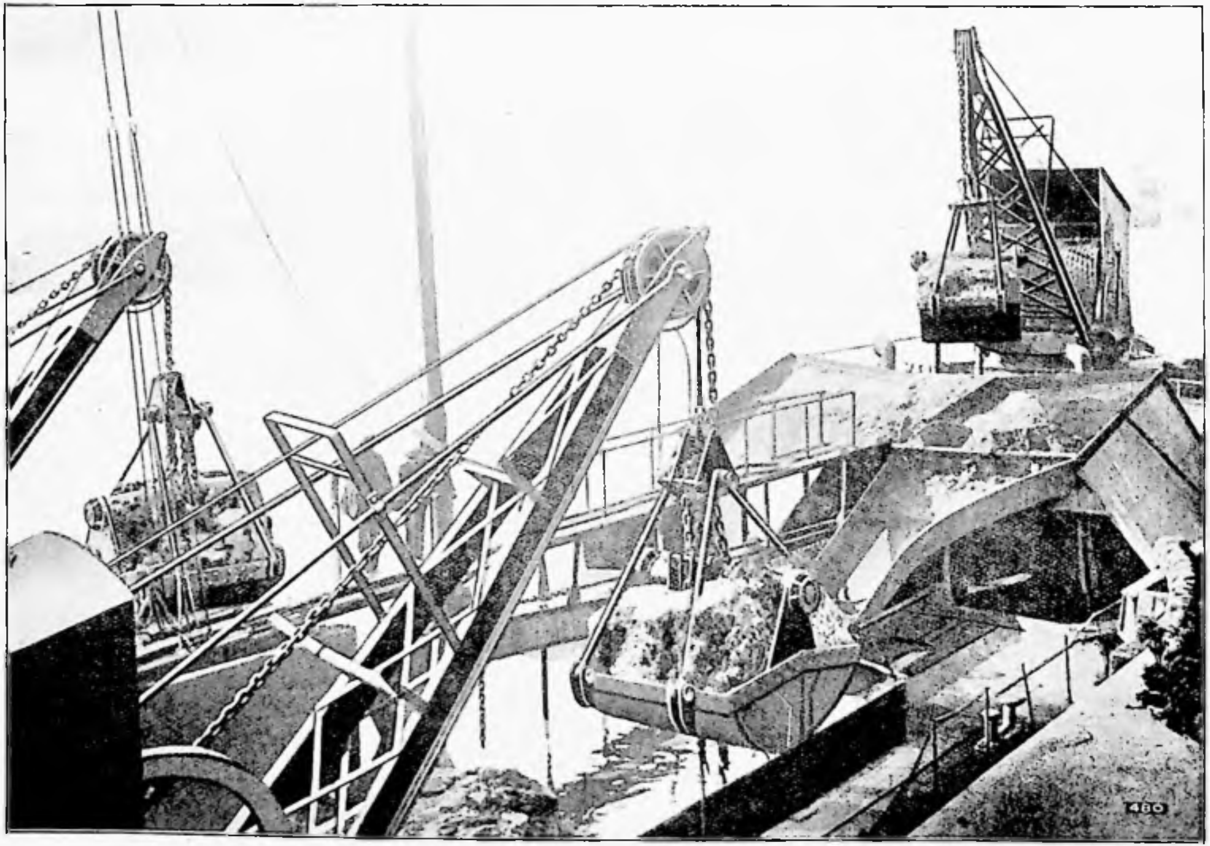
of years at many of the larger ports. The steam self-propelled grab hopper dredger is the type generally adopted, though in some cases grab cranes are fitted on dumb barges for the purpose of loading any ordinary hopper barge that may be available.

Stoppages and Repairs.—The dredging machinery of a grab hopper dredger is composed of comparatively small units, the number being in proportion to the size of the vessel. One of 1000 tons or thereabouts has four grab cranes with grabs complete. Should one grab or crane become deranged, the loading can be completed by the others, and should a bucket be seriously damaged, an occurrence which seldom happens, a spare grab can be fitted in a few minutes without affecting the dredging output. Damages may generally be repaired on board with spare parts, or with tools which are indispensable for the ship's engines, or if it is necessary to have recourse to the workshops, it is sufficient to unship the damaged crane and continue the work with the remainder, so that the loss of time is reduced to an insignificant minimum, when compared with the complete inutility to which other types of dredgers are subject. The grabs and cranes are of the double chain type, these being more satisfactory for the purpose in all respects than the single chain type.

It is essential that the grab bucket be designed to suit the particular material in which it has to work, the one for silt being of a light pattern formed of steel plates without tines.

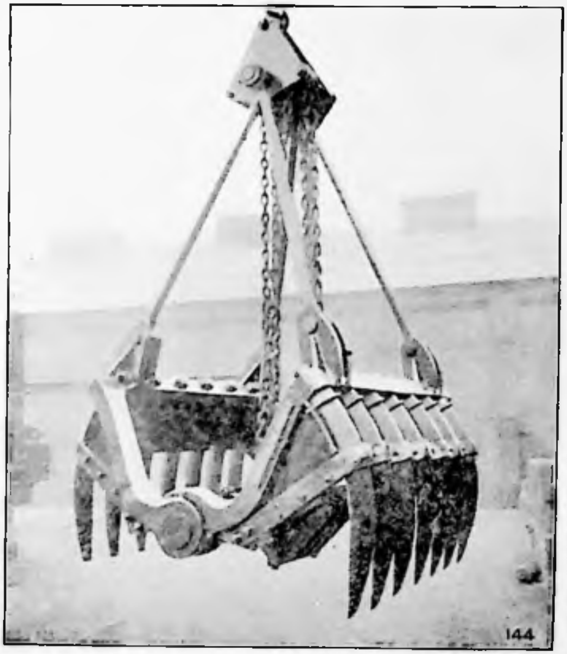
Grab Crane Design.—The cranes also are specially designed with large bearing surfaces, and of ample strength suitable for continuous work.

Cranes fitted on dumb barges generally have a steam boiler attached; this is also sometimes the case with those on small steam hoppers. The best practice, however, is to fit the cranes without boilers, steam being supplied from the vessels' main boilers. This allows the crane driver to work the crane continuously without interruption for stoking, etc. It also admits of the crane with its casing being kept within reasonable



Grab Hopper Dredger *Hessam*, in service of the Midland (now L.M.S.) Railway Company. Hopper Capacity 800 tons.
In this view the mud grabs of 80 cubic feet rated capacity are lifting 120 cubic feet of mud at each operation.

limits so as not to obstruct the sight of the navigators, at the same time giving more deckroom. Of the two chains fitted, one is used for closing the grab when on the bottom, for raising the loaded bucket to the top, and lowering while discharging. The other chain, or, as is generally the case, wire rope, is used for keeping the grab in an open position when discharging and while lowering to the bottom.



Whole-Tine Grab for Dredging Dense Sand, 60 cubic feet capacity.

The closing and lifting chain is attached to the main lifting barrel of the crane, the driving pinion of which is worked by means of a friction clutch. The opening rope is carried round a brake drum to an overhauling weight at the rear of the crane. This weight, when in action, is capable of keeping the grab in the open position, but is not sufficient to take all the weight, there being sufficient preponderance in the grab to

overhaul the main lifting drum together with the overhauling weight when lowering, the speed being regulated by the brake on the main lifting barrel.

An alternative method of operating the opening rope is by means of a barrel worked by a friction clutch, driven from the main hoisting barrel and mounted side by side with it on the same shaft.

The above methods of control allow the grab to be lowered gently through the water and mud to the dock bottom without digging in.

A grab designed for mud and having a capacity of 70 cubic feet, when resting on the bottom open, encloses an area exceeding 35 square feet. In the operation of lifting, the pull of the chain has the effect of relieving the bottom of the dock of the greater part of the weight of the grab when closing, the result being that no damage is done to the permanent bottom of the dock, which eventually in many cases might have a serious effect on the walls. The grab with its contents is lifted sufficiently high to clear the coaming of the hopper over which it is swung.

The operation of discharging is carried out by the crane driver, who holds the opening rope by means of the drum brake and releases the clutch of the lifting barrel pinion. The preponderance of the inner portion of the grab and its contents causes the grab to open and discharge its contents into the hopper. A shute or dashplate is generally fitted at the top of the hopper on which the mud is dumped. This breaks the fall and as far as possible prevents mixing of mud with the water in the hopper; the mud sinks to the bottom of the hopper and the water displaced flows overboard.

Each crane is capable of completing the cycle of operations, viz., slewing out, lowering, lifting, slewing in, and discharging, in one minute at a dredging depth of 55 feet.

Dock Traffic not Hindered.—It is a matter of importance that the work of removing mud should interfere as little as possible with the traffic and work carried on in the docks.

The grab hopper dredger satisfies this requirement to the utmost; it operates as follows:—

The dredger which has come into the dock with the last of the high water traffic does not commence work until the tidal traffic in the particular dock in which she has to work is completed, then light steel hawsers are run out fore and aft from the special winches with which she is provided, and the vessel loaded in about three hours, after which she proceeds to the gates where she awaits their opening before high water, in order to be locked out and to proceed to the dumping ground. She is thus out of the way during the time of busiest traffic in and out of the dock. The vessel returns from the dumping ground in time to enter the docks just before the gates are closed, and proceeds as before.

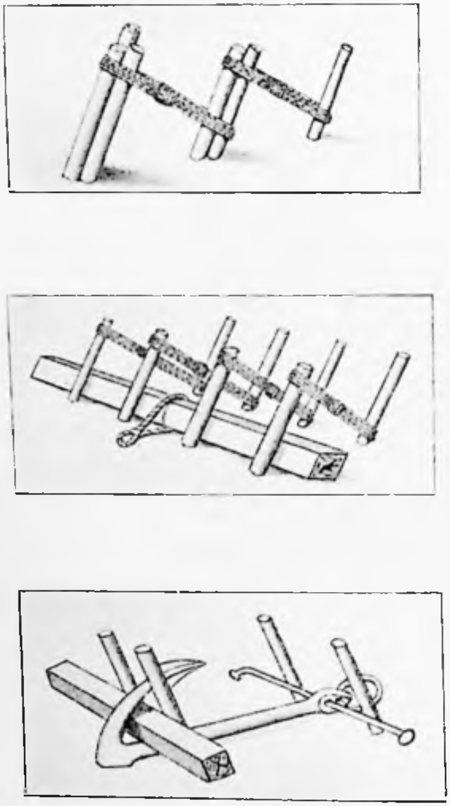
Other Types of Dredgers.—It is necessary, in order that the maximum load be taken out in a hopper, that the contents be kept as solid as possible, that is, the mud should not be broken up and mixed with water while being loaded.

The ladder bucket dredger which, perhaps, was the only type in use before the advent of the grab, with its attendant hoppers, is not so convenient a working tool in a dock. as it requires heavier moorings, often most difficult to arrange for the correct position for working, on account of the quays being occupied with cargo vessels. She cannot easily get out of the way of traffic, and does not leave the docks near high water when the traffic is heavy. The dredging cost per ton of a ladder dredger is about twice that of a grab dredger, owing to greater first cost, more costly maintenance and repair. This type of machinery, moreover, necessitates a much longer time out of commission for overhaul and repairs.

The remarks as to the use of a ladder bucket dredger on this class of work would also apply to a dipper dredger. In addition thereto would be the difficulty caused by garbage. such as pieces of ship's hemp and wire mooring ropes, and pieces of rigging, which, becoming threaded through the open bucket, would prevent the door closing properly and the catch

operating. The clearing of the door would cause considerable delay.

A suction dredger, it will be seen, is quite unsuitable for the purpose, as the mud becomes so mixed with the water as to be



A Method of Securing a Dredger's Anchors on a Foreshore.

incapable of settling in the hopper, and it is also found that fibrous and other material from the dock floor clogs the suction nozzle. Repeated experiments have been made with this method without success.

There is no doubt that a modern suction dredger, when loading with coarse sand such as will allow of the hopper being

Suction Cutter *Vizagapatam* built by Simons of Renfrew.

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filled in from 30 to 60 minutes or thereabouts, is the most suitable and economical vessel for the purpose, the cost per ton dredged being less than with any other type. But this condition does not always obtain; the nature of the sand varies, and it may be such that it takes hours to load the vessel; in one case which came to my knowledge a suction dredger which in one position in a harbour took 30 minutes, in another position took two days to load. This was owing to the fineness of the sand, which was difficult to penetrate by the suction pipe, and the discharge was so fierce that most of the material lifted was washed overboard with the overflow. In the above case a ladder dredger was substituted and this proved more satisfactory.

Grab Dredgers for Sand.—Later a grab hopper dredger, with grabs suitable for sand, was built and set to work with most satisfactory results. The sand, which was lifted in bulk and lowered in bulk into the hopper, did not get mixed with water as in the case of the suction dredger, and to a lesser extent in the case of the ladder bucket dredger. The grab is a suitable tool for sand, but it is essential that it be specially designed for that purpose.

The foregoing remarks refer principally to grab dredgers engaged on maintenance work, that is for maintaining docks, harbours, and rivers free from deposit, natural or otherwise.

Small Harbour Dredging and Other Work.—It frequently happens that in small ports and harbours where it is necessary to dredge a navigating channel, there is insufficient capital available for outlay on a dredger, hopper barges, and a tug. For such places the combined grab hopper dredger has a distinct advantage, as the entire work of dredging and the disposal of the spoil is done by one vessel.

There is also a large amount of work other than the above for which a grab dredger is suitable, if not the most suitable appliance, that is to say, for dredging where the material is of an alluvial nature.

There are many harbours and rivers, both at home and abroad, where the material is of this nature, and can be dealt with more effectively and more economically by the grab than by the more cumbersome ladder bucket and dipper dredger, and where the upkeep, especially abroad, of the comparatively small dredging units of the grab dredger are more within the bounds of the means at the disposal of those whose duty it is to maintain them in working condition.

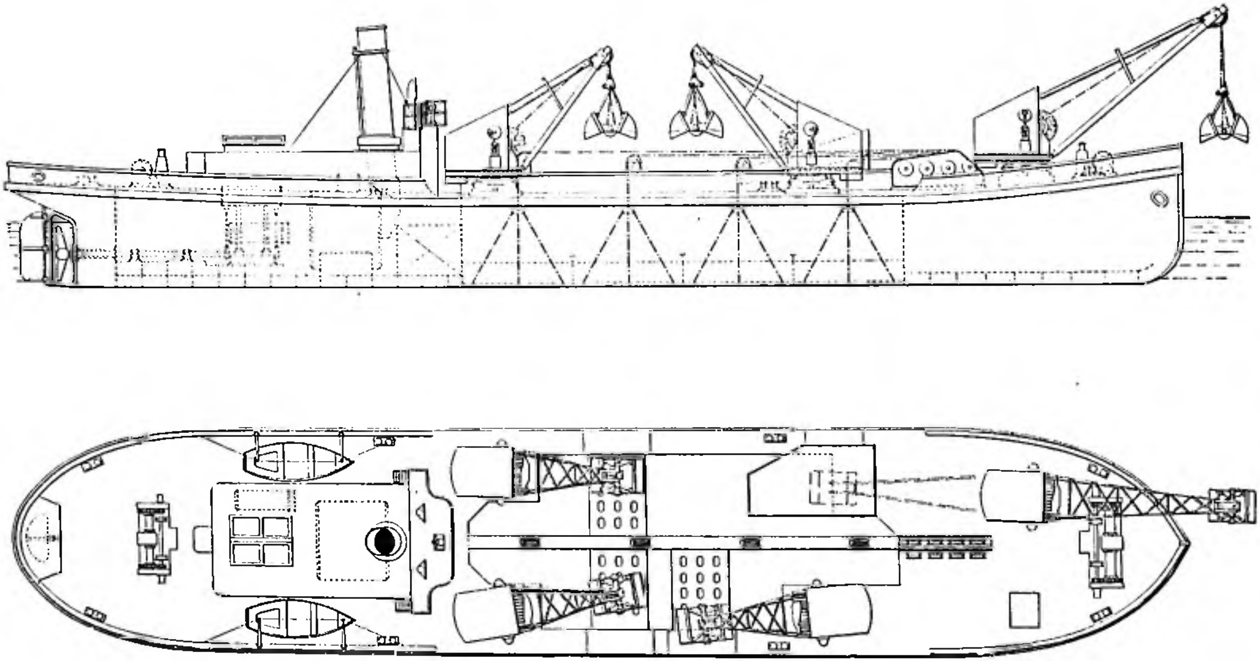
Depth of Dredging.—It is obviously a matter of some difficulty and expense to equip ladder, dipper, and suction dredgers to dredge at varying depths. The grab dredger has a great advantage for conditions where the working depth is varied, as it requires no alteration, addition, or adjustment, the depth of dredging only being limited by the amount of chain or rope which the hoisting barrel will hold.

Level Bottoms.—The criticism has been raised that the grab dredger does not dredge evenly. In practice, however, it is found that the work of a grab equals, if not excels, that of other types, any slight unevenness in the bottom of a dock or channel which may remain after dredging being quickly levelled by the wash of the water.

Rough Weather Work.—The efficiency of all types of dredgers depending upon hopper barges with tugs for the disposal of their dredgings is always reduced by stormy weather, which prevents the tugs and barges from proceeding to the dumping ground. The combined grab hopper dredger, on the other hand, is seldom held up by bad weather, its seaworthiness enabling it to continue its work while other types are idle.

The grab dredger may also work in the open in comparatively rough weather, as there are no fixed working parts below water. In the case of the ladder bucket dredger, where the ladder must be lowered to the bottom, this would, of course, be impracticable.

My remarks refer to the use of grabs for dredging material for which they are suitable. They point out that in all such



The Forward Crane may have a longer radius to facilitate dredging round the bow of the vessel.

[*By courtesy of Priestman Brothers, Ltd.*]

suitable cases, except that of coarse sand, they are the most economical, therefore the most suitable for the purpose.

We are indebted for the accompanying illustrations to Messrs. Priestman Bros. Ltd., Holderness Foundry, Hull, who made the grabs and cranes shown.

The vessels with their propelling machinery were constructed by various Clyde dredger and hopper builders.

Two 100-ton Bow Davit Lifting Lighters with Dredging Grab.

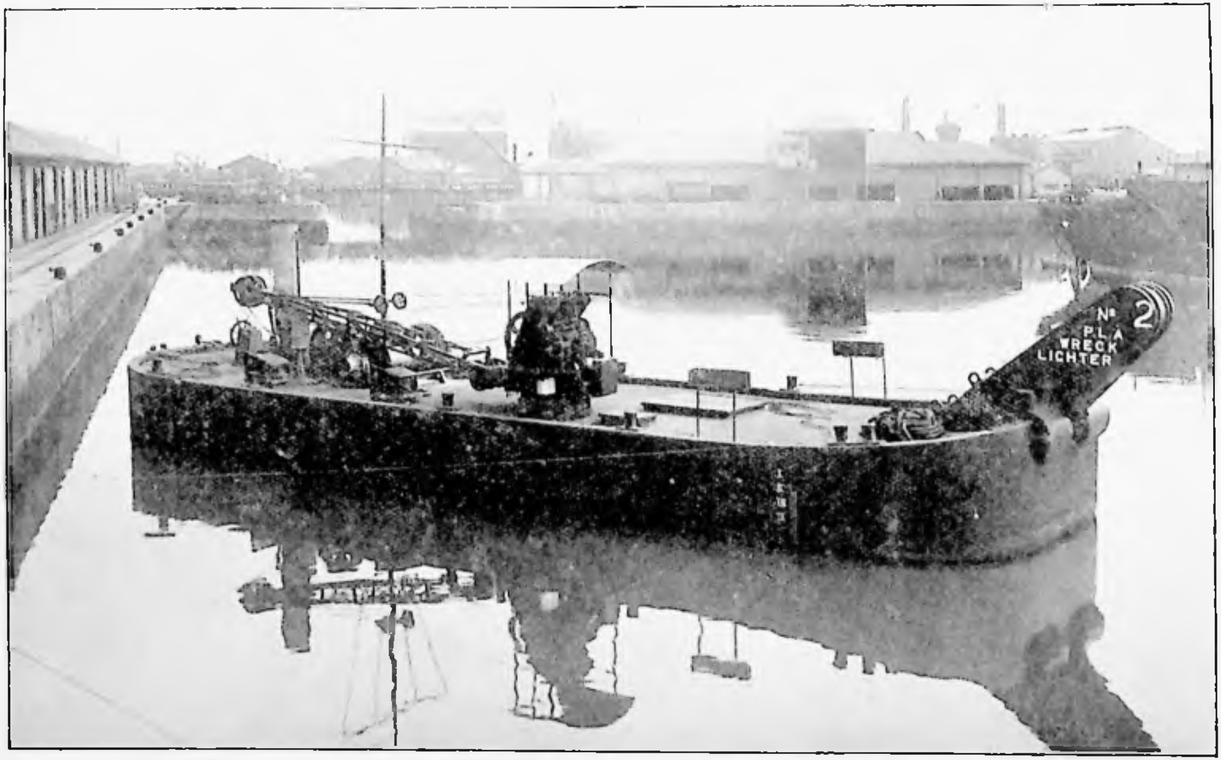
General Description of the Vessels and Account of the Trials.—The lighters are 90 ft. long by 27 ft. beam by 10 ft. 9 ins. moulded depth, having a very strong davit or horn at the bow and a powerful steam winch at the stern to enable submerged weights of up to 100 tons to be heaved up to the head of the davit. The lighters can also be used as floats or "camels," that is to say, they can be pinned down on an even keel to submerged wreck and then can give a tidal lift of 250 tons.

To take care of the great strains put upon the hull it has been built upon the longitudinal system of framing on the most modern principles, and is equipped with heavy wood bolsters and extra strong plating to resist the hard wear of wrecking operations.

The winch has two main barrels each of which can be operated independently, so that the full 100 tons can be lifted through 45 ft. with heavy four-ply purchase blocks from each barrel. The weight can be held and then taken on the second barrel and a second "fleet" taken; similarly, the load may be lowered independently.

When dealing with lighter loads a "fast gear" may be used on the winch and direct lifts without interposition of purchase blocks can be made up to 27 tons weight.

The exhaustive trials shewed that the winch had very ample power and was under full control. Using the fast purchase it raised 12 tons at the rate of 80 ft. per minute direct from the barrels.



100-ton Bow Davit Lighters, fitted with Grab Dredging Appliances
Constructed for the Port of London Authority by John Cran & Somerville, Ltd., Leith.

There is a steam driven salvage pump in the engine-room capable of pumping 480 tons an hour out of a sunken vessel to a height of 36 ft. This pump has pipe connections on the deck to which standard 10-inch flexible hose are to be fitted and a special valve box is provided to permit the use of two 7-inch suctions also.

Arrangements are made so that if circumstances required it, the whole pump can be disconnected and lifted as a unit out of the lighter by its own crane and put on the deck of a sunken vessel and connected by flexible steam pipes to the lighter's boiler.

There is further provision in the forehold to carry one portable oil engine driving 10-inch pumps of similar capacity.

There is a fire and ballast pump having a capacity of 28 tons per hour, which can pump from every part of the vessel and from a deck connection at the bow. This permits of draining the water from a barge or wrecked vessel which has been raised to the davit head.

This ballast pump can also deliver to the deck to the hose connection and into all ballast tanks and to the fire connection at the bows for washing out sunken craft, etc., moorings, etc.

The deck crane can lift 5 tons at 27 ft. radius to 27 ft. above deck from 40 ft. below water, and is equipped with a dredging grab of 40 cub. ft. flush loaded capacity. This is intended for discharging cargo, etc., from sunken craft, but can equally be used for ordinary dredging.

Each vessel is lighted by electricity and is equipped with four portable cargo clusters for illuminating operations above deck.

All of the auxiliary machinery has been well tested and found to be fully up to the requirements in every respect.

Suction Cutter Dredgers.—In contradistinction to the self-propelled self-loading suction cutters, there is the self-propelled but not spoil-carrying suction cutter. For many years the latter type has been in use. In 1911 Messrs. Lobnitz & Co., Ltd., built one of these vessels for dredging in the upper

White Nile to the order of the Egyptian Government. This vessel was designed by Mr. A. W. Robinson, M.Inst.C.E., Montreal, Canada. The vessel was shipped to Khartoum by sea and rail, and there erected; being self-propelling it was able to make the voyage up the river several hundred miles to the place where the work was in progress. The dredger was designed to make wide cuts in the bed of the river, and to deposit the spoil through a floating pipe-line having a shore discharge, the hull was made of steel, approximately rectangular, 162 feet long by 38 feet beam.

The machinery is mounted on the main deck and in the hold, the two upper decks being divided with accommodation for the officers and crew. A heavy steel suction frame is mounted in front upon the end of which is fitted a powerful rotary cutter adapted for dealing with stiff clays and heavy soils as well as softer material. The suction frame projects sufficiently to enable the vessel to cut its own floatation, through solid ground when necessary.

Two steel spuds, or vertical anchors, are fixed in slides near the stern, each having a sharp point near the bottom which holds in the ground and constitutes the anchorage for the vessel. The vessel is caused to oscillate from one side or the other of these spuds as a pivot, by means of side lines carried out from the forward end and attached to the shore. The cutter makes a lateral cut upon an arc of a circle, and has a clear swing from side to side of 150 feet; it can make a channel of this width by 25 feet in depth at one time.

The main machinery consists of a centrifugal dredging pump driven by a triple expansion engine of 700 h.p., together with complete auxiliary machinery.

The boilers are Babcock & Wilcox water-tube type, and the coal bunkers are arranged amidships, so as not to alter the trim of the vessel with varying load of coal.

The vessel is propelled by a stern paddle wheel, driven by horizontal compound engines of the usual type. The

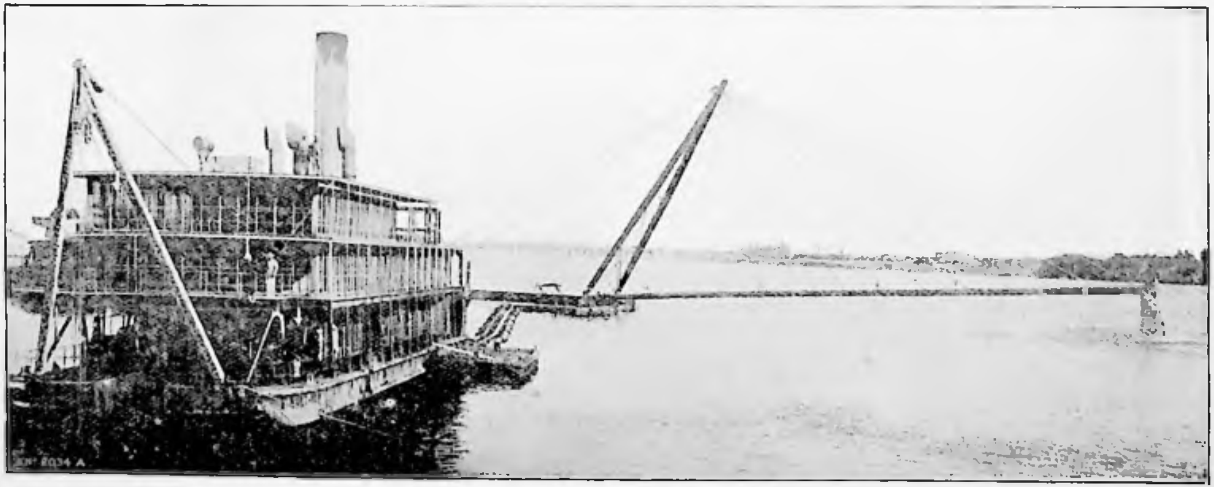


Fig. 1.—Dredger in Operation on the Nile.

under body of the hull is shaped or cut away forward and aft to facilitate propulsion, but is designed more for stationary dredging work than for navigation.

Suitable steering gear is arranged on the upper deck forward, where are also placed the levers and signals for operating the vessel when dredging. The discharge pipe consists of a number of flexibly connected floating sections and a terminal pontoon, from which the end of the pipe is suspended.

The overhang of the suspended portion may be as much as 200 feet if required, so that the spoil may be put well back in marshy places. The flexible joints are of the all metal self-packing ball joint, avoiding the use of rubber or leather sleeves. The rotary cutter is of the Robinson improved type, and is of cast steel, with renewable cutting edges. The blades are made of special form, to cut out heavy clay with as little resistance as possible and are self-clearing. The strength of each blade is sufficient to safely withstand the strain due to encountering immovable resistances when running at full speed.

We are indebted to Sir John Biles & Co. for some details of the suction cutter *Lord Willingdon*, recently delivered to the Port of Cochin for the maintenance of the 30-feet channel. The *Lord Willingdon* has a length of 207 feet, breadth 41 feet, depth 13 feet 4 inches, is self-propelled with a speed of 8 knots; working displacement 1695 tons on a draft of 9 feet 4 inches. Suction with cutter discharging through 4000 feet pipe-line pump capable of maintaining a total head of 75 feet. Discharging 1500 cubic yards per hour of coarse sand and stiff mud from a depth of 40 feet.

The diameter of suction is 42 inches; diameter of delivery 39 inches. The vessel is capable of working in a swell of about 2 feet. She has two stern spuds, on one or other of which she rotates when working in smooth water. The range of spring tides at Cochin is about 3 feet and at neap tides about $1\frac{1}{2}$ feet.

This dredger is not a spoil carrying dredger, the displacement referred to of 1695 tons being one of bunkers, machinery, waters and stores.

The *St. Lawrence*, a suction cutter working at Plymouth, has a capacity of 2000 tons approx.

The Dipper Dredger.—The dipper dredger is a modernised descendant of the spoon and bag dredger. Their use as important mechanical vessels are confined to America with occasional exception. They are fitted usually with spuds for mooring, thus enabling the vessel to creep along embankments without the aid of wire and/or chain moorings.

The working depth does not usually exceed 20 feet; although we are informed that greater depths are being designed for, and the *Onondaga* has a depth of 50 ft. The dipper arm with its bucket—sometimes fitted with teeth—is also used to assist in traversing the dredger from place to place, during which time the spuds are raised to permit of movement.

EXAMPLES (from *Kempfe's Engineering*, 1917).

For single scoop, capacity from 1 to 12 and 15 cub. yards; speed 30 to 40 secs. per bucket load in smooth water; speed 40 to 50 in open water.

Onondaga, New York Harbour.—140 ft. $\times$ 50 ft. $\times$ 15 ft.; bucket 12 cub. yards; 50 feet dredging; dipper arm 80 ft. $\times$ 36 ins. square; spuds for mooring=four timbers 80 ft. long $\times$ 5 ft. square; dipper arm and spuds of Oregon fir; engines double cylinder condensing; cylinders 20·5 ins diameter $\times$ 24 ins. stroke.

Panama Canal.—Two dipper dredgers each with buckets of 15 cubic yards capacity were built in 1914 by the Byars Coy. for Panama Canal. They have a displacement of 1500 tons, hulls of steel 136 ft. $\times$ 44 ft. $\times$ $15\frac{3}{4}$ ft. depth at bow; $13\frac{1}{2}$ ft. depth at stem. Each dredger has two dipper buckets, the larger of 15 cubic yards for soft material, and the smaller of 10 cubic yards for hard material. The buckets of $\frac{3}{4}$-inch plate have lips of manganese steel 2 ins. thick, which are 50 inches deep at the centre, reduced to $9\frac{1}{2}$ inches at the back edges. They have

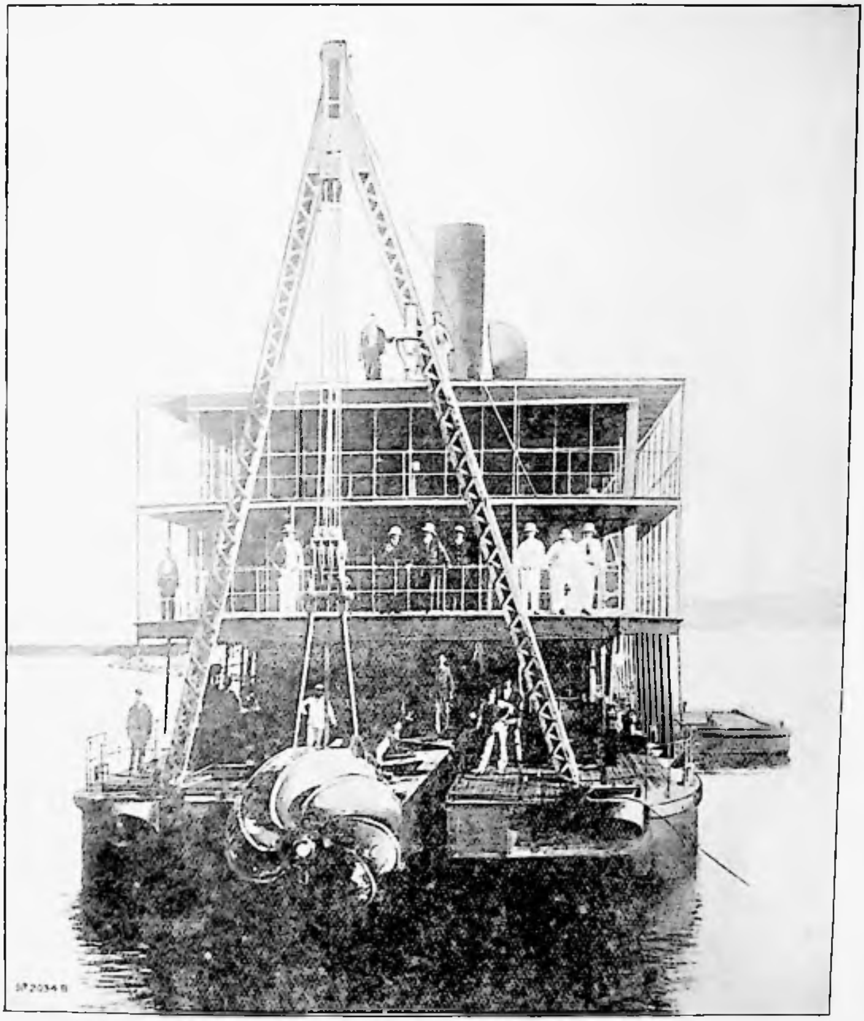


Fig. 2.—View Showing Rotary Cutter.

no teeth. The handles or arms are of Oregon fir 72 feet long. The rate of working in sand averages 6000 cubic yards, per day each, on 8 hours shifts.

In *Bombay Harbour*.—The *Walrus*, employed in Bombay Harbour, has a bucket capacity of 6 cubic yards, works to a depth of 40 feet, and is capable of raising boulders of over 12 tons weight.

Self-propelled Bucket Dredgers.—By courtesy of Ferguson Brothers Ltd. (Port Glasgow) we are able to furnish details of one of the larger self-propelled bucket hopper dredgers recently built in this country—the *Carronwater*, built for the London Midland & Scottish Railway. This vessel has a patent well-end. This patent well-end, broadly regarded, consists of an invention by which the accummulation of dead water at the junction of the breakwater and side walls of the wells, thus tending to improve the flow of water through the well.

The length of the *Carronwater* B.P. is 222 feet; breadth moulded, 43 feet; depth moulded, 17 feet 6 inches; mean draught loaded on trial, 13 feet 9 inches; block displacement, 2874 tons. In addition to the full speed runs on the measured distance a number of progressive tests were made.

The results are claimed by the builders to fully justify their claim for the reduction in propelling power in bow well dredgers fitted with the "patent stream well-end."

The contract speed was 9 knots; the full speed runs gave a speed of 9·66 with 988 i.h.p., 9·25 knots 840 i.h.p. At 9 (the contract speed) the i.h.p. was only 755. The vessel was loaded with 1250 tons of dredgings which were deposited in the hopper in 57 minutes; the buckets are of 23 cubic feet capacity. The main engines have cylinders 12 inches by 19 inches; 32 inches by 24 inch stroke.

The two boilers are of the cylindrical marine type, working at 180 lbs. pressure. The vessel has the usual complete set of auxiliaries installed, including a separate centrifugal pump, duplex pump, Weir's feed pumps, filter and auxiliary condenser.

The deck machinery consists of three multiple-barrelled

mooring winches of heavy construction, arranged to handle the head and side chains together or separately as required. The hopper doors are controlled by two sets of hopper door lifting engines, placed at the forward end of the hopper. The ladder is raised and lowered by a powerful hoisting engine and gearing placed on the forward framing. The worm wheel is of bronze, and the spur wheels are of cast steel having machine-cut teeth.

The main dredging gear is of massive construction, and consists of bevel and spur gears, with mild steel shafting in heavy bracket bearings leading from the main engine leading to top of the main framing.

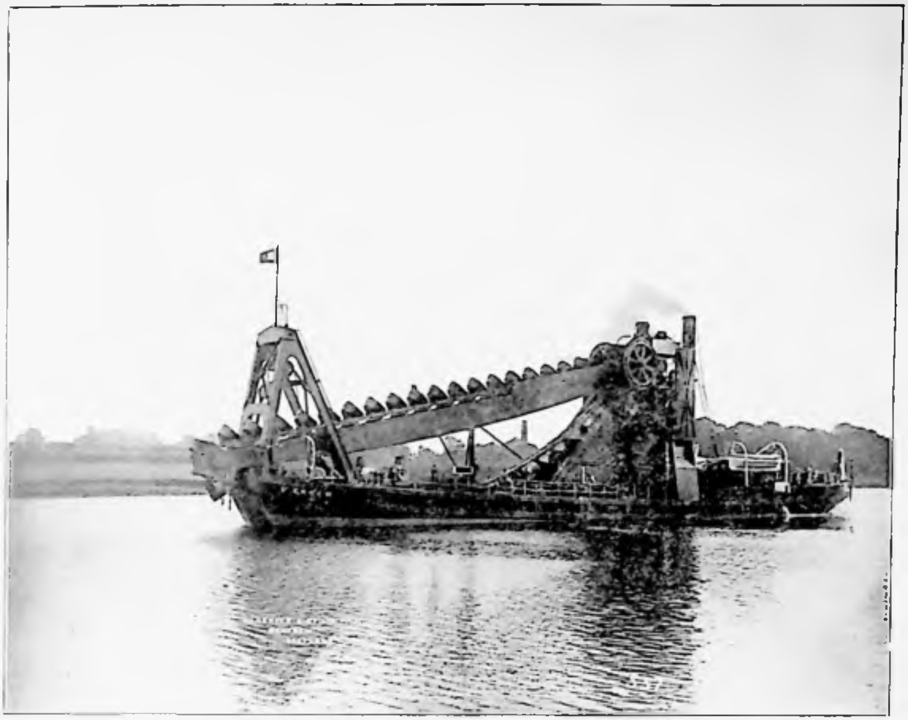
The buckets are of cast steel and special mild steel, with manganese steel pins and bushes.

With the open well-end the vessel is capable of cutting her own floatation.

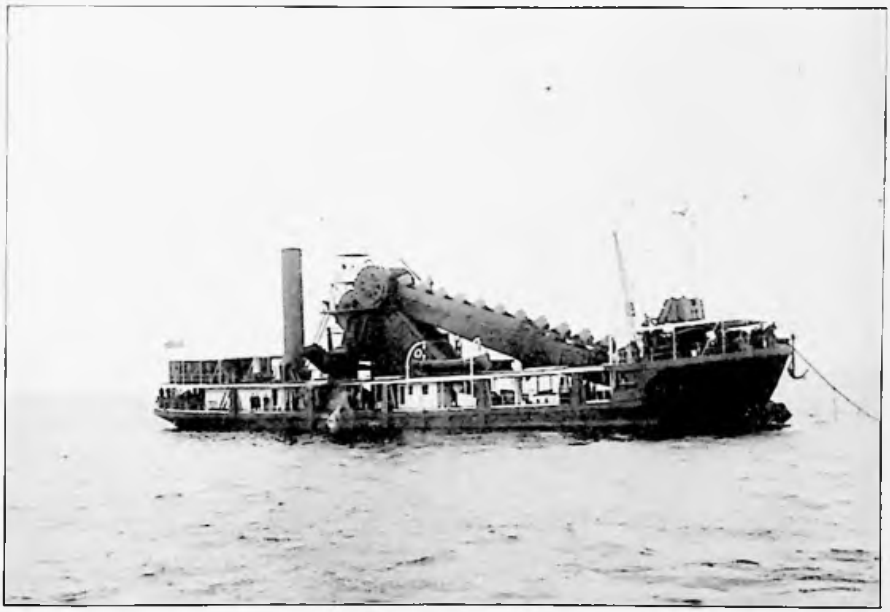
Life of Top Tumblers.—The top tumbler of a bucket dredger is probably the hardest worked unit of machinery in the vessel—the strains and reflex conditions to which it is subject may be said to consist of compression, sudden release of load, torque, shock, transverse and longitudinal bending moments. Can it be wondered therefore that a variation in the working life of these mechanical parts is considerable. There are mainly two types of top tumblers used at the present day speaking metallurgically: (1) high carbon cast steel; (2) manganese steel. For several years we used high carbon cast steel top tumblers having a tensile strength of 45 tons per square inch and a Brinnel hardness factor of about 215. It may be here noted that manganese steel has a little lower factor, but its resistance to abrasion is greater to an extraordinary degree.

When working in mud, clay, chalk, and occasionally conglomerate, we have found that the average life of ten consecutive high carbon cast steel tumblers was 1500 hours, and the amount of wear $3\frac{1}{2}$ ins.

A 27 Cubic Feet Bucket Dredger.—An experimental manganese steel tumbler was fitted and worked for the extremely long



Twin Screw Sea-going Bucket Dredger *St. Enoch*.
Built for British Admiralty by Lobnitz of Renfrew.



Dredger *Barbus* with Buckets of 32 ft. Capacity.
Built for Bombay Port Trust by Simons of Renfrew.

period of 6380 hours, retaining its shape to the end. On another occasion the manganese tumblers failed after 222 hours, but its successor ran for 3600 hours, to be followed by one which ran for 4100 hours. These 222, 3600, 4100 hours were registered on a smaller type dredger working in chalk and clay.

A 15 *Cubic Feet Bucket Dredger.*—A common practice in operating has been to keep the high carbon cast steel tumblers at work until the driving faces became so worn down and rounded that the tumbler begins to miss in its function of rotating the bucket chain.

Manganese steel tumblers have been seldom found to require renewal from abrasion; they call for renewal through cracking internally as a rule.

A (14 *cubic feet bucket*) dredger working continuously in gravel used three successive manganese steel tumblers having lives of 2320, 2520, and 5220 respectively in contrast to one high carbon steel which ran 1500 hours and wore to $3\frac{1}{2}$ ins. during the commission of the dredger.

B^1 (10 *cubic feet buckets*) dredger working in mud and silt used two manganese steel tumblers which ran to 3401 and 11,071 hours respectively as compared with 2518, 2100, and 1350 hours—3 ins. wear with high carbon tumbler.

B^2 dredger working in mud, gravel and silt used a manganese steel tumbler which ran for 8900 hours compared with high carbon steel tumblers which ran 3580, 3700, 1700 and 1200 hours respectively wearing away to 3 inches.

As actually made for commercial purposes manganese steel contains about 12 per cent. of manganese and 1·50 per cent. of carbon. Although the presence of 1·50 per cent. of manganese makes steel relatively brittle, and although a further addition at first increases this brittleness, so that steel containing between 4 and 5·5 per cent. can be pulverised under the hammer, yet a still further increase gives very great ductility, accompanied by great hardness—a continuation of properties which

was not possessed by any other known substance when this remarkable alloy, known as Hadfield's manganese steel, was discovered. Its ductility, to which it owes its value, is profoundly affected by its rate of cooling. Sudden cooling makes the metal extremely ductile, and slow cooling makes it brittle.

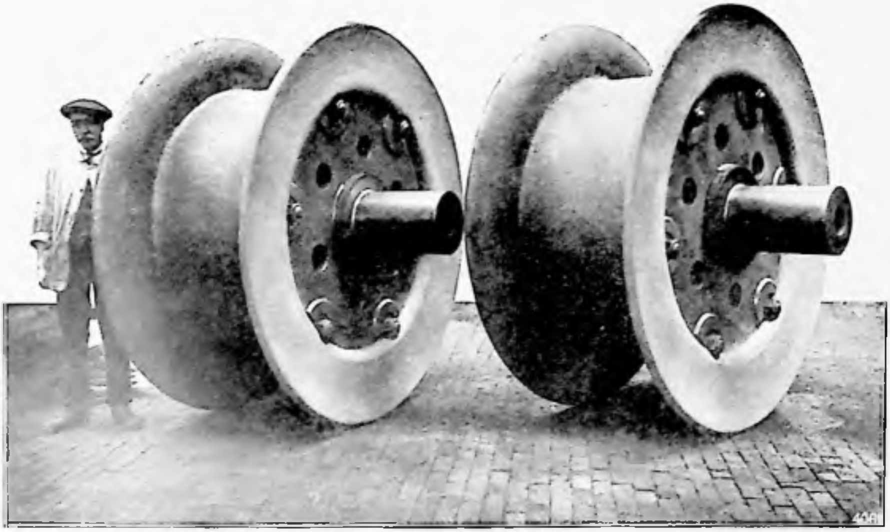
The accompanying table of hours worked shews the great variation in life of these tumblers, and is taken from the normal records kept with a view of considering the relative values of the metals, together with cost and efficiency.

TOP TUMBLERS OF DREDGERS.

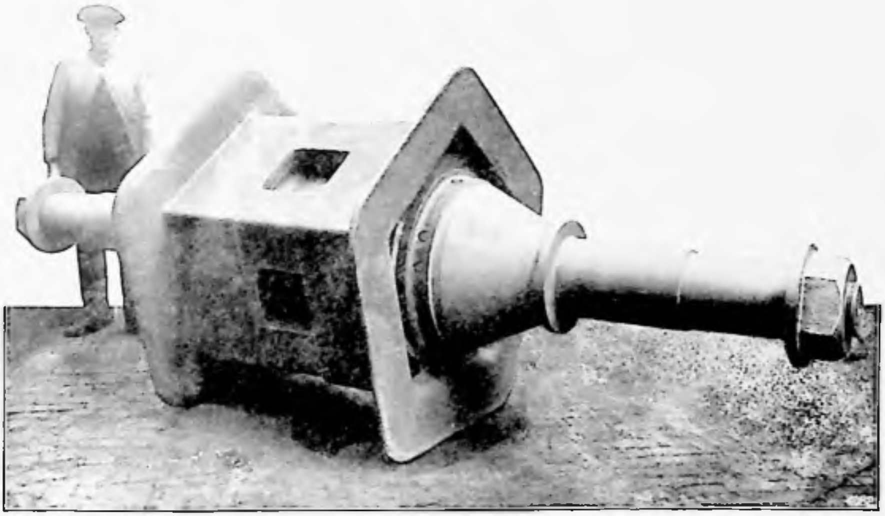
No. of Hours worked by "Era" Manganese Steel and High Carbon Steel Tumblers.

Vessel	Number of Hours Worked.			
	Index No. of Tumbler	"Era" Manganese steel	Index No. of Tumbler	High Carbon Steel
Dredger No. 30			10	2800
			11	4800
			12	2940
Dredger No. 45	29	3401	23	3580
	30	3102	24	1633
			25	3700
			26	1360
			27	1700
			28	1250
Dredger No. 67	50	6360	42	3200
	51	2280	43	2700
	52	2000	44	1360
	53	2000	45	1720
	53A	1436	46	1700
		——	47	1304
		5)14076	48	1620
		——		1640
	mean	= 2815⅕	49	——
		2520		8)15244
Dredger No. 10A.	1			——
			mean	= 1905½
				——
Dredger *Persia*			82	5440
			83	3300

Quadrantal or Pentagonal.—In our observations and figures dealing with the longevity of top tumblers and whether high carbon steel or manganese (Hadfields' "Era") we have confined the statistics to the square face or quadrantal top tumbler.



Bottom Tumblers made by Hadfields Ltd. of Sheffield.



A Top Tumbler of Hadfields' "Era" Manganese Steel with Shaft.

There is, however, a strong opinion in favour of the pentagonal tumbler. It is quite definite that the pentagonal top tumbler is gaining in popularity. Its advocates point out that the bucket chain mounts and leaves the pentagonal tumbler more smoothly than from the square one in proportion to the difference between the heights of the two segments. Not only is there less impact on a tumbler of this form, but it is claimed that it results in less wear and tear of pins and bushes, diminished by the reason of the more obtuse angle.

The pentagonal tumbler wears less quickly than the square one, because it has one more face, the weight of the bucket chain having more faces than one; and what is still more important, the alleviate support afforded by uneven number of faces makes for more regular wear over a greater surface than is afforded by a square faced top tumbler.

Finally, the rotation of the bucket is normally slower with the pentagonal tumbler, or rather, the tipping period is slightly longer as compared with a square faced tumbler, hence the bucket has more time to discharge its contents into the shoot, resulting in less spilling.

Supervision and Care of Tumblers, Bucket Chain and Ladder Gear.—The condition and maintenance of the above deck dredging gear and specially the ladder gear is best regulated by a fixed routine.

Top Tumblers.—These should be inspected at least daily, and when reaching a condition for renewal several times daily. The wear on the canting edges should be measured weekly and the change registered in a proper manner.

Lower Tumblers.—The lubrication of these units is of special importance and a forced lubrication arrangement is common to-day. The ladder should be raised at least twice a week for inspection and lubrication. When working alongside dock walls where rubbish is thrown into the dredged area, the lower tumbler may require clearing from wires and old rope, the accumulation of which impairs the running of the tumbler and bucket chain.

Buckets, Links and Pins.—It is the usual custom to number these, the number with date of renewal being entered in the log, thus ensuring a precise record of wear and tear. Constant supervision of these parts is necessary, and as they can be viewed during the rotation of the bucket chain renewals are commonly made during suspension of the excavating and other opportunities which experience suggests.

Leading Extracts from Specification for a 27-Cubic Feet Dredger.

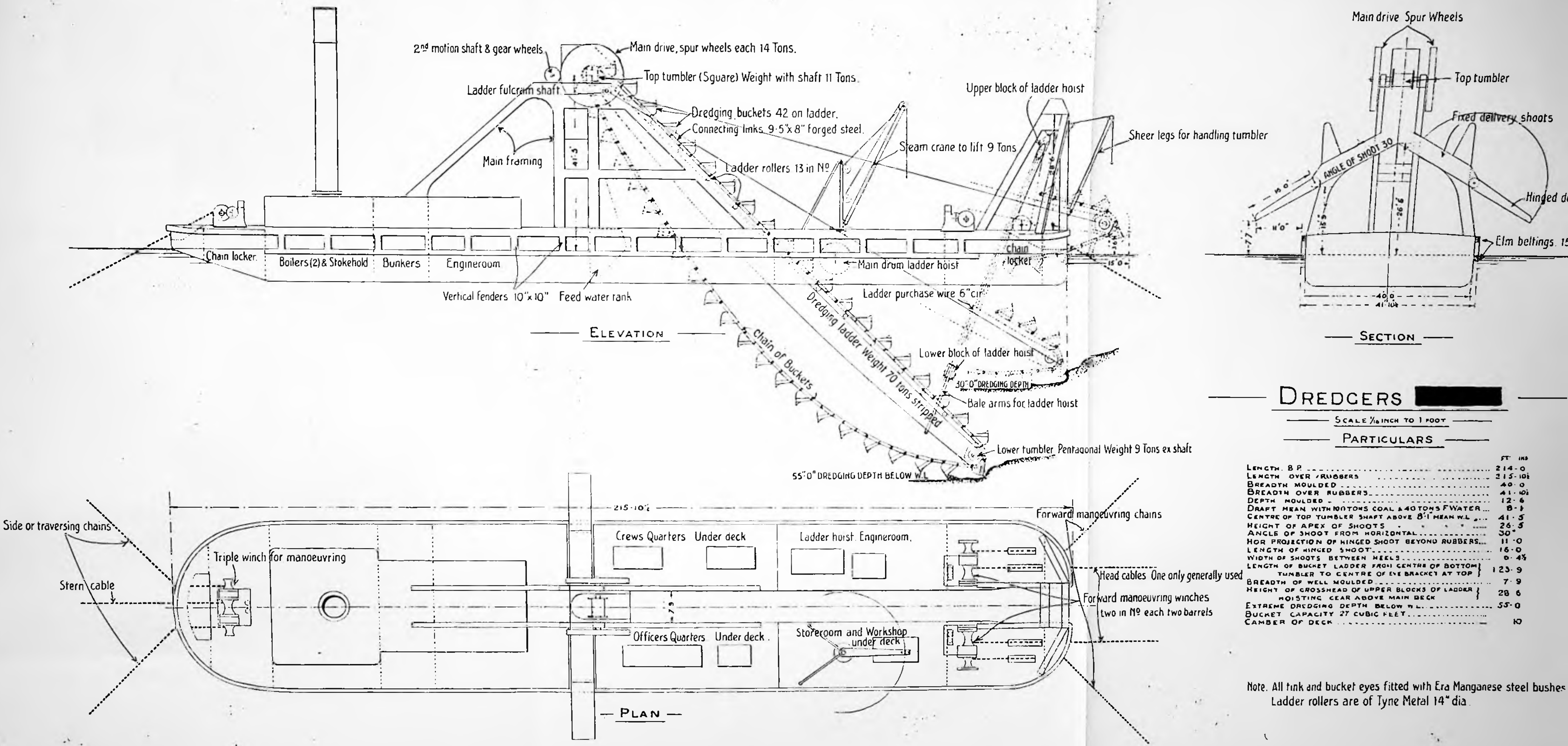
Type and Capacity.—The dredger to be a non-propelling centre ladder, open bow well, bucket dredger, capable of dredging and discharging into steam hopper barges on either side 765 cubic yards of sand, gravel or stiff clay per hour when working at a maximum depth of 55 ft. below water level. The dredger is to be capable of cutting its own flotation and dredging to a depth of 30 ft. below water level in a vertical line with bow. The dredger is to be so designed and equipped with mooring winches and tackle that it shall work with full efficiency when dredging against or with the current of the river and discharge into a hopper barge of 1000 cubic yards capacity, 215 ft. 0 in. long by 35 ft. 6 in. beam, by 19 ft. 0 in. moulded depth, moored to the dredger.

The dimensions, proportions and form of the hull generally to be such as to ensure its being thoroughly stable when fully equipped and in working condition.

The bucket ladder to be of sufficient length to enable the buckets to reach the maximum dredging depth, but the angle of the ladder shall not exceed 45 degrees from the horizontal.

The fore framing is to be of such a height that the lower pins of the hoisting links may be raised clear above the deck and the lowest portion of the bottom tumbler to be 3 ft. 6 in. above the waterline.

The shoots are to be of ample width, having a declivity of 30 degrees from the horizontal, and so arranged that the



DREDGERS [redacted]

SCALE 1/16 INCH TO 1 FOOT

PARTICULARS

	FT. INS.
Length. B.P.	214-0
Length over rubbers	215-10½
Breadth moulded	40·0
Breadth over rubbers	41·10½
Depth moulded	12·6
Draft mean with 100 tons coal & 40 tons F Water	8-1
Centre of top tumbler shaft above 8'1" mean W.L.	41·5
Height of apex of shoots	26·5
Angle of shoot from horizontal	30°
Hor projection of hinged shoot beyond rubbers	11·0
Length of hinged shoot	16·0
Width of shoots between heels	0·4½
Length of bucket ladder from centre of bottom tumbler to centre of eye bracket at top	123·9
Breadth of well moulded	7·9
Height of crosshead of upper blocks of ladder hoisting gear above main deck	28 6
Extreme dredging depth below W.L.	55·0
Bucket capacity 27 cubic feet	
Camber of deck	10

Note. All link and bucket eyes fitted with Era Manganese steel bushes
Ladder rollers are of Tyne Metal 14" dia.

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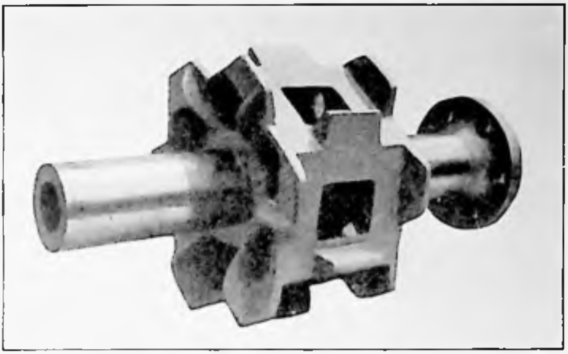
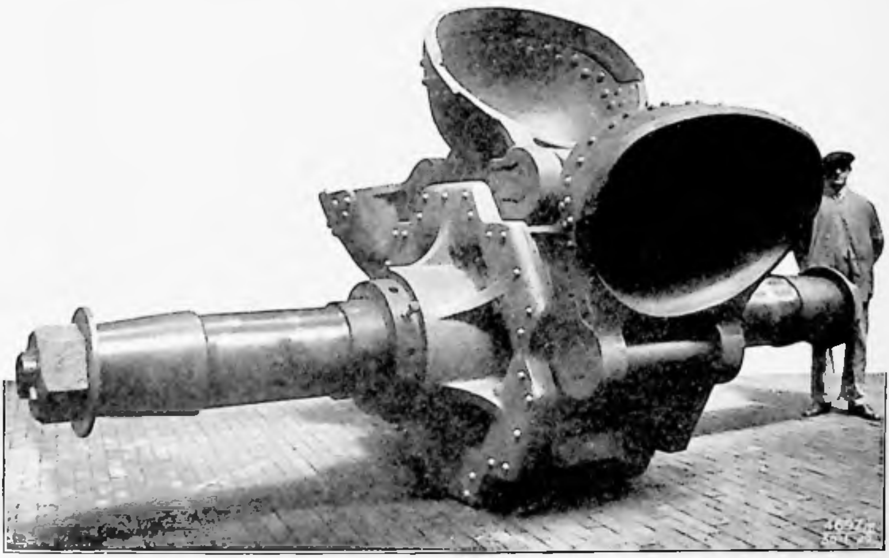
A BUCKET DREDGER WITH PRINCIPAL PARTS INDICATED.



Hexagonal Top Tumbler for Close-connected Bucket Chain in use on Ohio River on Dredgers of the Dravo Coy. of Pittsburg.



Hadfields' Top Tumbler and Shaft with Close-connected Buckets in position.

dredgings may be discharged over either side of the dredger or over both sides simultaneously.

Machinery.—The bucket ladder is to be raised and lowered by means of a powerful engine operating by gearing on to a winding drum with steel wire rope leading around a set of five sheave blocks hung from the fore framing.

Three steam mooring winches to be fitted on deck, one at each bow and one at the stern. The moorings to be led over fair-leads so arranged that the moorings are not more than 3 ft. above the water line at the point where they leave the dredger.

The bucket chain is to be worked by a set of marine type compound surface-condensing engines, through a system of spur and bevel gear; two powerful and efficient friction clutches or surge wheels to be fitted on the shaft of the top tumbler. When working at full capacity the speed of the engine is not to exceed the rate of 80 revolutions per minute, and they are to be of ample power to do the work with steam pressure of 150 lbs. per square inch, and the slide valve of the high-pressure cylinder cutting off steam at not later than 70 per cent. of the stroke. The engines are to be capable of being worked with steam at 160 lbs. pressure.

A change gear is to be provided to vary the speed of the bucket chain from 17 to 10 buckets per minute. The condensing plant and feed pumps are to be independent of the main engines and a complete equipment of auxiliary engines is to be provided, including an engine for working the shoots.

Two marine type boilers to be fitted, each of ample dimensions, and each capable of supplying all the steam required to operate the dredger at full power.

A steam-driven dynamo to be fitted and the dredger to be illuminated throughout by incandescent lamps provided on a liberal scale.

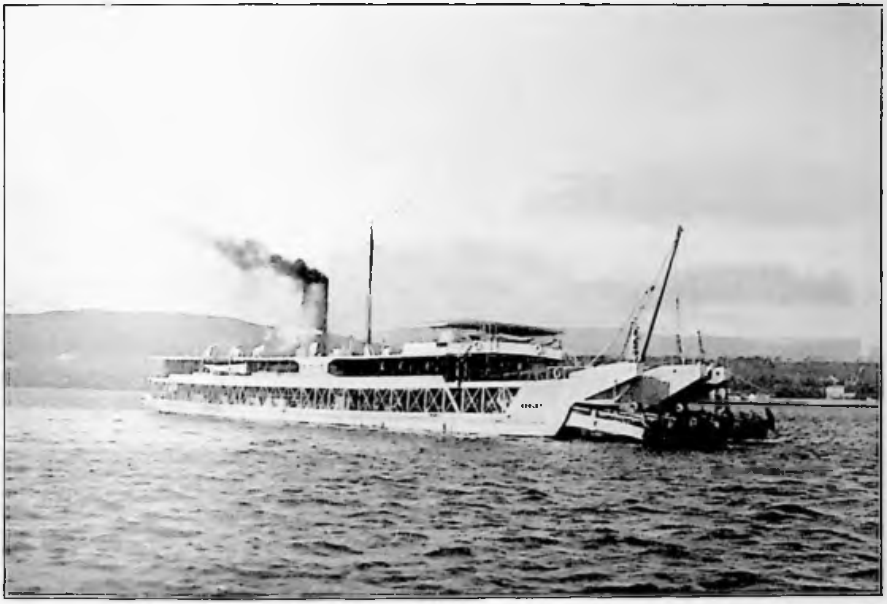
Watertight Bulkheads.—The hull is to be divided into nine watertight compartments by steel bulkheads, all carried up to the main deck, properly stiffened and made watertight, suitable spaces forward and aft to be arranged as chain lockers.

Accommodation.—Cabins and mess room to be provided for the officers on one side of the well, the other side to be fitted up for the accommodation of the crew, all under the main deck. The accommodation to be well arranged and comfortably furnished. The lighting and ventilation of the cabins, etc., to receive special attention. On the side of the well opposite the hoisting engine a compartment to be fitted up as workshop and store room. On deck two w.c.'s, a large galley, lamp room, and a room for the surveyor to be fitted in the engine casing, the height of this casing to be 7 ft. above the deck.

Scantlings and Classification.—The dredger is to be built of steel under Lloyd's Special Survey, together with the whole of the machinery and boilers, and is to be classed 100 A1 dredger. The scantlings of the plates and bars of the hull are to be in no case less than 6/20, in every instance to be not less than hereafter specified, and fully up to the requirements of Lloyd's for a deep-sea vessel of the same dimensions. In addition, the boilers and their mountings are to be constructed under the survey of the Board of Trade.

The dredger is to be measured by the Board of Trade, and Lloyd's certificate of class and a "special certificate" from the Board of Trade to be obtained and supplied by the builders.

Dimensions.—	ft.	in.
Length over all	215	8
Length between perpendiculars	214	0
Breadth moulded	37	0
Depth moulded	12	6
Sheer	None	
Camber of deck	0	$9\frac{1}{4}$
Height of centre of top tumbler shaft from waterline	40	0
Height of apex of shoots from waterline ..	25	0
Angle of shoots from horizontal not less than ..	30 deg.	
Horizontal projection of hinged shoot from moulded breadth line	12	0



Multiple Suction Cutter Dredger *Cowley*, built by Simons of Renfrew.

Length of hinged shoot to fold up inside line of deck	16	0
Width of shoots	6	0
Length of bucket ladder from centre of bottom tumbler to centre of eye brackets at top about	122	0
Moulded breadth of well	7	9
Height of crosshead of upper blocks of ladder hoisting gear above main deck	27	0
Extreme dredging depth below water level ..	55	0
Dredging capacity per hour when dredging sand, gravel or stiff clay ..	765 cub. yd.	
Mean draft of the vessel with 100 tons coal in bunkers, 40 tons of fresh water in feed tanks, and all stores and spare gear on board must not exceed	8	6

Trials.—After the dredger has been delivered at the appointed place the contractor is to carry out a dredging trial and trials of all the auxiliary machinery. For this purpose the dredger is to be placed by the contractor at a place in the river indicated by the Harbour Board's officers, and two trials of the dredging capabilities are to be made there. The moorings are to be placed in position and the dredger is to be worked during the trials by the contractor, who shall pay all expenses in connection therewith, but the Harbour Board will provide the barges to receive and carry away the dredgings.

(1) The dredger is to fill into two 1000 cubic yard hopper barges at the rate of 765 cubic yards per hour with sand, gravel, or stiff clay when working at a maximum depth of 55 ft. below water level. During this trial the main engines are not to exceed 80 revolutions per minute, and the cut-off of the high-pressure slide valve is not to be later than 70 per cent.

The dredger is to be moored during these trials head down stream. One trial is to take place during the full ebb tide with 1000 cubic yard hopper barge moored to the dredger.

The second trial is to take place during the full flood tide with 1000-yard hopper barge moored to the dredger.

The rate of dredging is to be computed by measuring the volume of the material filled into the barges during a period of one hour into each barge. The first barge is to be moored on the port side and the second to be moored on the starboard side of the dredger.

The ladder is to be hoisted right up and lowered on to the beam over the well at the end of each trial.

(2) All auxiliary machinery is to be well tested.

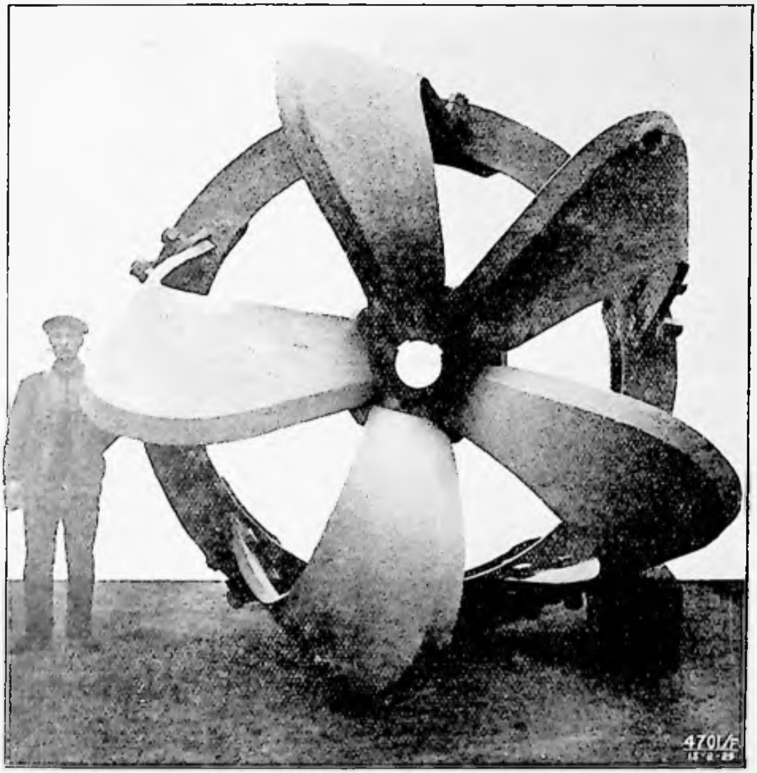
(3) The dynamo is to be kept running during the whole of the time of the dredging trials and the whole of the lamps are to be burning.

Drawings.—All detailed drawings of the hull, machinery, boilers and fittings, without exception, are to be submitted to the Harbour Board for approval before the work is proceeded with. The Harbour Board will be at liberty to furnish additional or detailed drawings as the work proceeds, and such drawings to be worked to by the contractors as forming part of the contract.

The contractors will be required, on completion of the work, to furnish the Harbour Board with a complete and correct set of drawings, all in triplicate, viz., one set of tracings on cloth and two sets of photo prints on cloth. He is also to supply an analysis of the weights of the constituent parts of the hull, machinery and outfit.

Insurance.—The contractors to keep the dredger, its machinery and equipment, fully and specifically insured, both ashore and afloat, under Lloyd's "All Risk" policies. The policies to be handed to the Harbour Board before each instalment is paid.

Maintenance or Guarantee Period.—The contractors will be held responsible for the efficiency of the vessel and its machinery for a period of six months after it has been accepted by the Harbour Board after delivery, and any parts which during this period may be found defective, or showing signs of weakness,



Revolving Cutter for Dredger fitted with Blades of
Hadfields' "Era" Manganese Steel.

or undue wear owing to faulty design, materials, or workmanship, must be removed by the contractors, and the defects made good at their expense. Due allowance will be made for fair wear, tear, or accident.

Main Engines.

Description.—To be one set of marine three-cylinder tri-compound surface condensing engines, having one high, one intermediate, and one low-pressure cylinder, with one crank to each cylinder. The dimensions and stroke of the pistons to be such that when turning at 80 revolutions per minute and the slide valve of the high-pressure cylinder cutting off steam at 70 per cent. of the stroke the engines will develop sufficient power to drive the bucket chain when working in sand, gravel, or stiff clay, and dredging at the rate of 765 cubic yards per hour.

Lubrication.—Cast brass syphon lubricators with hinged brass lids to be fitted on sides of cylinders and on each main bearing with shut-off cock to each pipe. Pipes to be 5/8ths in. diameter led to all motions. Oil cups on top and bottom ends, eccentrics, slide rod guides and tumblers to be of large size. Substantial brass lubricators to be fitted to all other working parts of both main and auxiliary engines. Special attention should be given to all parts requiring lubrication. One 20-gallon and two 10-gallon oil economiser tanks of approved rate to be fitted up in engine room. Brass watch tank with brass save-all to be fitted up.

Boilers.

General Description.—To be two in number of the cylindrical multitubular type, each having three corrugated furnaces of the withdrawable type with Gourley-Stephen necks. To be constructed to the requirements of Lloyd's and Board of Trade for a working pressure of 160 lbs. per square inch, and each to be capable of working the dredging machinery at full power.

Main Gearing.

First Motion.—At forward end of crank shaft a short length of shafting with solid forged coupling to be fitted with two substantial feathers. Shafts to be $9\frac{1}{4}$ ins. diameter in the body and $7\frac{3}{4}$ ins. diameter at the journals. A high-speed and low-speed pinion wheel are to be mounted on this shaft and to be moved in and out of gear by a strong screw, single thread $3\frac{1}{2}$ in. diameter by 1 in. pitch working in a renewable gun-metal nut 5 in. long fixed in the boss of wheel. Boss of wheel to be 26 in. long.

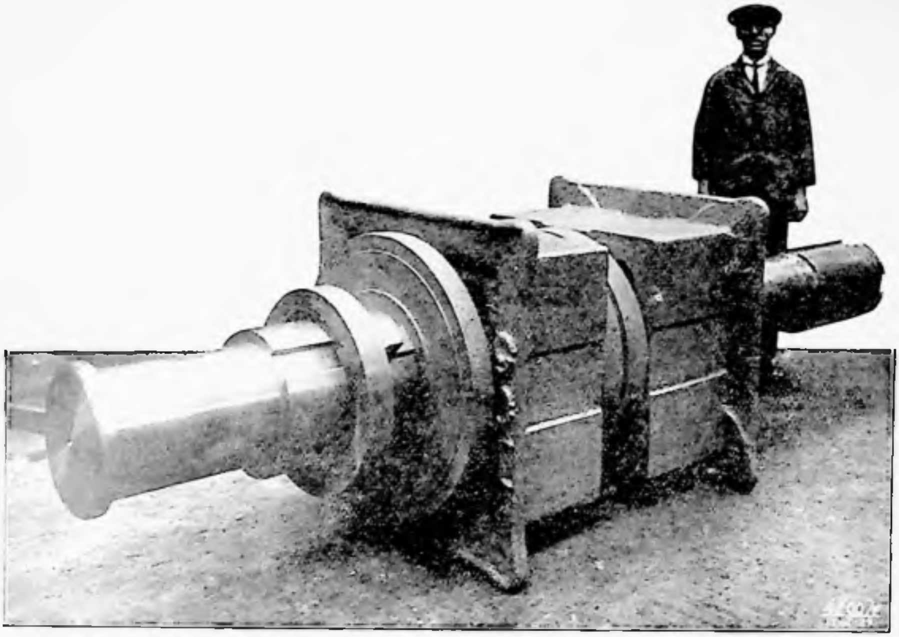
First-motion wheels to have about 31 and 37 teeth pitched $3\frac{1}{2}$ in. by $9\frac{1}{4}$ in. broad and to be full capped on one side.

Second Motion.—Shaft to be $9\frac{1}{2}$ in. diameter outside of bearings, $10\frac{3}{4}$ in. diameter between bearings, and $9\frac{1}{2}$ in. diameter at journals. To have high and low-speed spur wheels firmly keyed thereon, having about 59 and 65 teeth respectively, $3\frac{1}{2}$ in. pitch by $9\frac{3}{4}$ in. broad, full capped on one side.

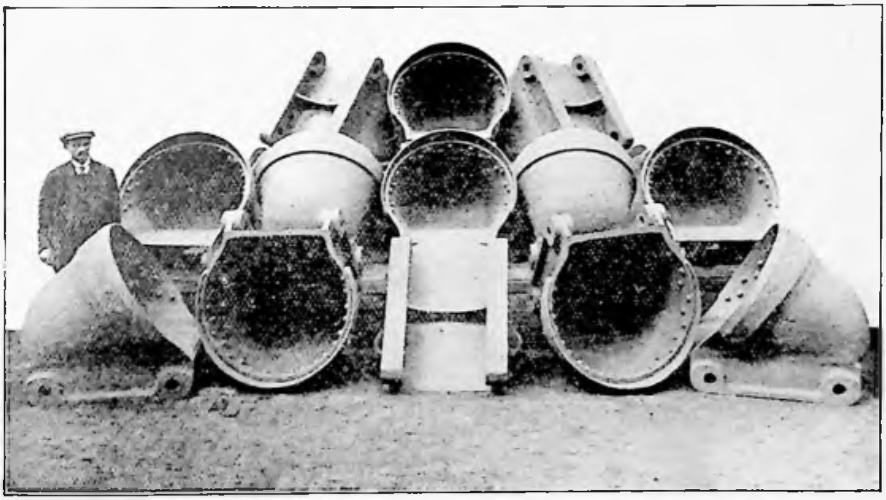
At forward end of the shaft a bevel wheel to be fitted, having 24 teeth $4\frac{3}{4}$ in. pitch by 13 in. broad, half capped. Wheel seat to be $10\frac{3}{4}$ in. diameter and a solid collar to be forged on shaft behind the sheel.

First and second motion shaft journals to work in flat-backed bearings lined with brasses 1 in. thick and fitted with adjustable covers. Bearings to be cast with strong brackets securely bolted together, and to heavy seating built into the structure of the ship. Brackets to be bedded on teakwood soles accurately fitted. At forward end of second motion shaft a strong bracket with bearing of similar construction 18 in. long to be fitted.

Vertical shaft to be $9\frac{3}{4}$ in. diameter in two lengths with solid forged coupling. At bottom end to be swelled to $11\frac{3}{4}$ in. diameter in wheel, and to work in strong footstep fitted with adjustable gun-metal shoe. Immediately above the bevel wheel, which is to have about 40 teeth and is to gear with that on the second motion shaft, a bearing of similar construction to the others is to be fitted. This bearing is to be contained in a



Top Tumbler (Square Type) for River Dredger of Hadfields' Patent "Era" Manganese Steel fitted on Shaft of Hadfields' Forged Steel.



Dredger Buckets of Toughened Cast Steel fitted with Era Manganese Steel Lips.

bracket casting securely bolted to a cross tie 24 in. deep by 20 ins. broad, strongly bracketed and riveted to the vertical legs of the main framing. A spur stay to be fitted from this bearing to that on the horizontal shaft.

A second bearing of a similar construction to be fitted at the height of the horizontal bracing of main framing and attached to a box tie 21 in. by 15 in.

At top of vertical shaft a third bearing to be fitted of strong construction securely attached and fitted between two box ties each about 24 in. by 16 in., securely bracketed and riveted in main frame.

At top of vertical shaft a bevel pinion having about 26 teeth $5\frac{1}{4}$ in. pitch by $14\frac{1}{2}$ in. broad to be fitted gearing into a spur bevel having about 38 teeth on the cross shaft. Shaft to be swelled under wheel seat to $11\frac{3}{4}$ in. diameter.

Cross shaft to be $12\frac{1}{2}$ in. diameter in pinion and bevel wheels, $9\frac{1}{4}$ in. diameter in journals, and $11\frac{1}{2}$ in. diameter in body; journals to be 16 in. long.

Two pinion wheels to have 27 teeth $5\frac{3}{4}$ in. pitch by 14 in. broad.

Two main spur wheels to have 98 teeth $5\frac{3}{4}$ in. pitch by 14 in. broad. Each spur wheel to have a loose rim mounted on friction centre 10 ft. diameter and fitted with cast iron shoes brass lined. Main spur wheels and centres to be of special cast iron. All other wheels to be of cast steel, and all teeth to be capped and to be turned on points and edges of teeth and on the capping Bosses of spur wheels to be reinforced with heavy forged steel rings accurately machined and shrunk on.

Brackets to carry cross pinion shaft and top tumbler shaft to be of cast iron substantially built, accurately machined, keyed and bolted together. To be fitted with flat-backed bearings of gun-metal all round the journals secured by forged steel keeps and through collar bolts. Brackets to be bedded down on teakwood soles accurately fitted and to be secured by numerous bolts through the rider plate and top and bottom angles of main framing with thick ferrules between.

Tumblers.—Top tumblers to have four sides and circular flanges 4 ft. 6 in. diameter, to be of Hadfield's toughened cast steel. Flats of tumbler to be $3\frac{1}{2}$ in thick, flanges to be $2\frac{3}{4}$ in. thick at root and 2 in. thick at edge. To be provided with heavy bosses accurately bored to fit the shaft, and to which the casting is to be shrunk and secured by two keys at each end, each fitted with efficient stoppers.

The outer end of each boss to be strengthened by a strong mild steel ring accurately machined and shrunk on after the tumbler has been put in place on the shaft.

Top tumbler shaft to be a solid ingot steel forging machined all over, $16\frac{3}{4}$ in. diameter in the body, 18 in. diameter in the bosses of tumbler, and $14\frac{1}{2}$ in. diameter in the journals, which are to be 20 in. long. To be secured to the main spur wheel by two keys accurately fitted and checked by stoppers. Boss of the wheel to be strengthened by two mild steel rings accurately machined and shrunk on in place.

Bottom tumbler to have five sides and large circular flange 6 ft. 3 in. diameter and to be of Hadfield's toughened cast steel. Flat of tumbler to be 3 in. thick, flanges to be 3 in. thick at root and $2\frac{1}{4}$ in. thick at the edge. At the corners of each cant of the tumbler the flanges are to be thickened up on the inside by a pad 1 in. thick, cast with the tumbler. Bottom tumbler shaft to be a solid ingot steel forging machined all over, 13 in. diameter in the body, 16 in. diameter in the bosses, and 13 in. diameter in the journals. To be secured in the tumbler by two large keys at each end. Ends of shaft to be fitted with cast steel sleeves machined and shrunk on and secured by strong dowel keys through the ends of the shaft, all so as to be renewable. Sleeves to be $3\frac{1}{2}$ in. thick.

Lubrication of all bearings to have special attention and ample splash guards to be fitted around all gear wheels to prevent grease being thrown about. Save-alls to be fitted to catch oil drips.

All shafting to be solid steel forgings.

Each of the wheels and pinions is to be secured to its shaft

by two large keys and fitted with stoppers in the approved manner.

Suitable platforms to be fitted round upper tumbler and alongside main framing where required having double rails, stanchions, and suitable ladders.

Ladder End Brackets.—At lower end of ladder strong cast steel brackets to be accurately fitted and secured by turned and fitted bolts with double nuts. Ends of brackets to have jaws to receive chilled cast iron bearings $5\frac{1}{2}$ in. thick to carry tumbler shaft, secured by strong cast-steel keeps fitted with bolts having double nuts. Bearings to be 22 in. long and arranged with check cast on, and fitting in recess in the steel casting to prevent end motion.

Ladder Rollers.—The bucket chain to pass over rollers 14 in. diameter spaced about 10 ft. apart on the top side of the ladder. The rollers to be of "Tyne metal" or other approved material of equal hardness, and to be fitted with turned mild steel spindles secured by a key at each end and fitted at journals with cast steel thimbles, $1\frac{3}{4}$ in. thick, working in bushes of chilled white iron fitted to cast iron brackets with shell covers. One half of the rollers to have deep flanges to guide the bucket chain.

Buckets.—To be of 27 cubic feet capacity. The backs and bottoms to be of cast steel with the links cast on. The back and bottom to be 1 in. thick; the flanges of the link portion to be $1\frac{3}{4}$ in. thick, webs $1\frac{3}{4}$ in. thick, bosses for the pins to be 6 in. thick and $9\frac{1}{2}$ in. diameter. Body plates to be of mild steel 5/8 in. thick with lip plate $1\frac{1}{4}$ in. thick. Cutting lips of Hadfield's "Era" manganese steel to be riveted to the lip plates and to be 48 in. wide by 21 in. deep, projecting 8 in. beyond the lip plate and to be $1\frac{3}{8}$ in. thick.

Rivet holes in castings, body and lip plates and cutting lips, to be drilled accurately to template and all rivets to be of steel and closed by hydraulic pressure. The cutting lips are not to be heated in any manner after receipt from the makers. Bosses of links to be fitted with Hadfield's "Era"

manganese split steel bushes 5/8 in. thick and to be thickened up in the direction of wear.

Links.—To be forged solid from Siemens-Martin acid steel blooms of machinery quality. To be $9\frac{1}{2}$ in. deep by 8 in. thick at ends and 4 in. thick at middle. The centres of link pins to be 39 in. apart, and the length of the reduced portion at middle to be 18 in. Holes to be accurately bored to gauge and fitted with Hadfield's "Era" manganese split steel bushes 5/8 in. thick. The links are to be set 29 in. apart athwartship centre to centre.

Hoisting Gear for Bucket Ladder.—The lower end of ladder to be suspended by a wire rope tackle from the head frame. The hoisting gear to consist of five upper and five lower cast-iron sheave blocks, the pulleys of which are to be 48 in. diameter. The sheaves of top blocks to be fitted with phosphor bronze bushes, 7/16 in. thick, and those of the bottom block with bushes of Hadfield's steel $\frac{3}{4}$ in. thick. The upper sheaves to work on a massive forged steel crosshead standing across the top of head frame. The lower sheaves to work on a pin of Hadfield's toughened steel secured in the frame of the block, which is to be of forged steel. The crosshead and pin to be bored axially and radially and fitted with Stauffer grease cup at each end. A steel crosshead to be fitted in the frame of the lower block and to be connected by forged steel links to a crosshead fixed in heavy eye brackets bolted to the under side of the ladder, which is to be fitted with heavy doubling plates in way of same.

The wire rope to be of extra flexible plough steel, the barrel to be of cast iron with spiral grooves accurately moulded and to be sufficiently large to take in the whole rope without riding and three turns more. The barrel to be driven by worm and worm wheel and cast steel spur gear actuated by a two-cylinder reversible engine having cylinders 13 in. by 13 in. diameter by 15 in. stroke.

Preventer Rope.—A preventer rope is to be secured to the lower end of each side of the bucket ladder, and to be lashed

to the brackets for rollers when not in use. Strong fair-lead sheaves to be arranged on the aft leg of head frame, so that the preventer ropes may be brought over them and coupled to purchases worked from the winches. The ropes and their fastenings to be strong enough to lift the ladder and bucket chain.

Mooring Winches.—Three powerful steam mooring winches to be fitted, one at each bow of the dredger and one at stern. Each bow winch to have one end chain barrel and one side chain barrel of the surge barrel type, and of approved form, arranged to be driven independently or together, and each fitted with a powerful band brake lined with hardwood $1\frac{1}{4}$ in. thick; each winch to have a warping barrel on second motion shaft. The chain barrels to be fitted with hard steel whelps sunk in the bodies of the barrels and secured by set pins; the outer ends of the chain barrel shaft to be carried up by strong forged steel brackets fitted with gun-metal bushes. To have the necessary clutches, levers, etc., and to be fitted with two-speed gear.

Fair-leads.—An independent fair-lead for each mooring chain to be fixed at the end of dredger in such manner that the chain shall not be more than 3 ft. above the waterline at the point where it leaves the dredger. Head and stern fair-leads to be strong iron castings fitted with a heavy cast steel bush 3 in. thick secured in the casting and through which the chain passes, bush to be renewable. Fair-leads for side chains to be strong castings having large vertical rollers of "Tyne" metal, fitted so as to be renewable, and lubricated by Stauffer grease cups. Horizontal rollers $6\frac{1}{2}$ in. diameter to be fitted to the outside of each fair-lead and to be fitted with Stauffer grease cups.

The hull to be suitably formed to give direct lead of chains from fair-leads to chain barrels and chain pipes of extra large diameter to be bolted on deck to lead chains to lockers.

Spare Gear for Dredging Machinery.

4 Hunting links
6 Buckets complete
20 Cutting lips of Hadfield's "Era" manganese steel
6 Ladder rollers of "Tyne" metal
6 Bucket links
100 Hadfield's link pins
200 Hadfield's link bushes
200 Hadfield's bucket bushes
1 Complete set of chilled bushes for ladder rollers
1 Complete set of sleeves for ladder roller spindles
8 Chilled cast iron bushes for lower tumbler shaft
8 Cast steel sleeves for lower tumbler shaft
1 Each of the bevel wheels in main gearing, of cast steel
2 Sets of pinion and clutches for one winch
2 Side chain barrels for one winch
1 Set of piston packing rings and springs for each mooring winch and the hoisting engine

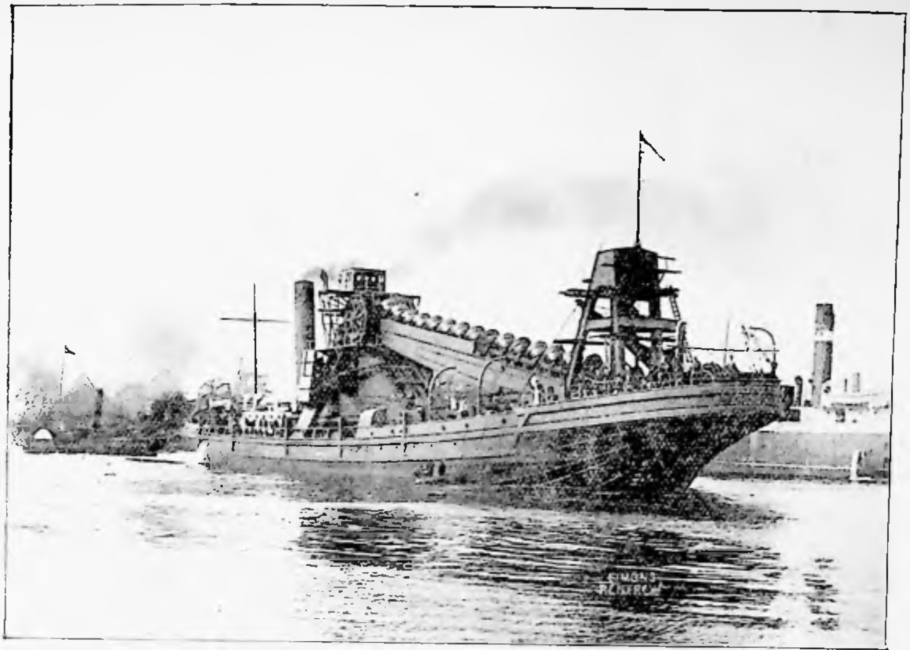
General Description.

Bucket Ladder.—To be of sufficient length to enable the bucket to reach to a depth of 55 ft. below the waterline when at an angle not exceeding 45 degrees.

To be constructed of best class girder work formed of two longitudinal web plates ·60 in. thick and 7 ft. deep at middle of length, having double steel angles 5 in. by 5 in. by ·70 in. and a rider plate 12 in. by ·80 in. thick, riveted to both angles.

The web plates to be tied together by solid diaphragm plates ·50 in. thick spaced about 7 ft. apart having angles 4 in. by 4 in. by ·50 in., riveted to web plates and diaphragms and riveted to cross-tie plates top and bottom. Where these angles are butted an angle of the same size is to be fitted on the opposite side of the diaphragm plate for the full depth of the web.

Cross-tie plates top and bottom to be ·50 in. thick and 2 ft. wide between the webs and where riveted to the rider plates they are to be 3 ft. 6 in. wide.



The U.S. Government Dredger *Corozal*, built by Simons of Renfrew.

The Dravo Coy. Dredger on Ohio River.

A strong box tie to be formed at each end of the ladder with top and bottom plates ·75 in. thick, vertical plates to be ·60 in. thick and angles 4 in. by 4 in. by ·50 in.

Longitudinal web plates to be in long lengths and where butted to have double treble riveted butt straps fitted.

Longitudinal angles to be in lengths of not less than 30 ft. and to have bosom pieces 3 ft. long at the butts.

Fore Framing.—To be formed of four legs, two at each side of the well at fore end, to be 24 in. by 15 in. by ·45 in., having angles 4 in. by 4 in. by ·5 in. The forward legs to be vertical, carried down and strongly bracketed to well side and deck. Aft legs to be raked and to extend through the deck to a strong seating and bracketed thereto.

Top of framing arranged as a deep girder to carry the crosshead of hoisting blocks. A deep tie-plate on the fore side to be carried down and spread over the bows of the dredger so as to form an efficient tie.

Cranes.—A steam-driven derrick crane to be fitted on the starboard side capable of lifting 9 tons, having wire rope lifting and topping purchase with two speeds on the former, foot-brake, slewing gear, and all necessary fittings. A sheet-iron hood to be fitted over driver's platform.

Anchors and Chains.—

2 Bow anchors, Byers' patent stockless, each 60 cwt.
1 Stern anchor, Byers' patent stockless, 60 cwt.
4 Side anchors, Byers' patent stockless, each 40 cwt.
500 Fathoms 2 in. short link chain cable for bow anchor.
400 Fathoms 2 in. short link chain cable for stern anchor.
800 Fathoms $1\frac{3}{8}$ in. short link chain cable for side anchors.
90 Fathoms $3\frac{1}{2}$ in. circumference flexible steel wire rope in two lengths with reels.
90 Fathoms 6 in. manila hawser.
90 Fathoms $4\frac{1}{2}$ in. manila warp.
2 Heaving lines.
240 Fathoms 6 in. flexible steel wire rope in 4 lengths, with eyes and shackles on each length.

o

Shoots.—The width of the shoots to be 6 ft. 0 in. and to be carried on the main framing and formed of steel plates and angles, the angles to be 3 in. by 3 in. by ·3 in. and the plates ·3 ins. thick.

Bottom of shoots to have doubling plates ·7 in. thick, and the sides to have doublings ·3 in. thick, secured by countersunk headed bolts; flat strips to be fitted over the angle bars also. Top edge of side plates to be finished with a $2\frac{1}{2}$ in. by $1\frac{1}{4}$ in. half-round riveted thereto. The hinged portion to fold up within the moulded breadth line, and to project 12 ft. horizontally from the moulded breadth line when lowered to 30 degrees inclination. The side plating of the fixed shoots to extend to deck, and the whole to be of substantial construction. The top of the fixed shoot to be covered with plating ·3 in. thick, properly stiffened. The underside of the hinged shoot to be stiffened by two wood fenders 5 in. by 4 in., secured between angles 3 in. by $2\frac{1}{2}$ in. by ·3 in. Hinges of shoots to be extra strong, with bolts having heads of large diameter, with nut and washer butting against shoulder. Doubling plates to be fitted to side plates in way of hinges. Outer end of hinged shoot to be raised by two-wire purchase led over deep rimmed pulleys to barrel of hoisting engine; each barrel of which is to be worked by clutch and brake independent of the other.

Shoot Door.—A tumbling door to be fitted at apex to direct dredgings to either side. Door to be a steel casting with hinge pins cast solid with it, and to work in a steel casting bolted to the apex of the shoots. Doubling plates ·75 in. thick to be hung on this door on each side by eye-bolts and shackles. End of shaft to project through back of screen with quadrant lever and counter-weight attached. To be operated by strong wire ropes lead over pulleys to foot of shoot frames, so that a lead may be taken to the barrel of the mooring winches.

Shoot Screens.—A hood screen to be fitted at top of main framing formed of steel plates ·25 in. thick, suitably stiffened by angles $2\frac{1}{2}$ in. by $2\frac{1}{2}$ in. by ·25 in., with hinged lid on top, and

all so arranged as to be portable to permit of lifting out top tumbler and shaft.

At back of main framing and sides down to deck to be of steel plate ·3 in. thick, suitably stiffened by vertical angles or flanged plates, and at back to be fitted with doubling plates ·7 in. thick, secured thereto by countersunk headed bolts. A hinged door to be fitted at deck level on one side for inspection purposes.

Brief Outline Specification for a Steel Non-Propelling Barge-Loading Dredger for Specially Dredging River Silt and Gravel.

General Description.—The dredger is to be constructed of steel and is to have a single ladder with its chain of buckets working in a well formed at one end in the centre of the hull. The position and size of the well to be arranged to suit the dredging gear and to give ample room for the machinery, winches, hoisting gear, etc.

The dredger is to be capable of dredging in its own depth of water, cutting its own flotation, and at any depth down to 70 feet below the water level when the angle of the bucket ladder to the horizontal must not exceed 50 degrees.

The dredger is to be capable of raising and delivering into barges on either side not less than 500 tons of ballast gravel per hour when dredging at a depth of 70 feet.

The top tumbler is to be set at sufficient elevation to permit the shoots to be at an angle not less than 30 degrees to the horizontal; the hinged parts must deliver at a height of 6 ft. at 8 ft. from the side of the dredger and must be lowered and raised in 60 seconds.

The ladder lifting gear must be arranged so that when the ladder is raised to its highest position the bottom tumbler will be clear out of the water.

The buckets are to be of 12 cubic feet capacity.

The engines are to be triple compound surface condensing

marine type, of ample power to drive the bucket chain at a speed of 22 buckets per minute when working in gravel.

Two boilers are required of the marine return multi-tubular type, each capable of independently working the dredger and having $3\frac{1}{2}$ square feet of heating surface for each indicated horse-power of the dredging engine; their working pressure is not to exceed 180 lbs. per square inch.

The hull of the dredger is to be rectangular in plan, with well rounded corners at bow and stern, and to have strong wood belting at the gunwale and strong steel sampson posts faced with hard wood at intervals along each side, and with steel plate bulwarks and strong steel bar rail between. The freeboard when fully loaded with bunker coal and fresh water and in working order should not be less than 4 ft. 6 ins.

Coal bunkers of 40 tons capacity and feed water tanks of 12 tons capacity are to be provided.

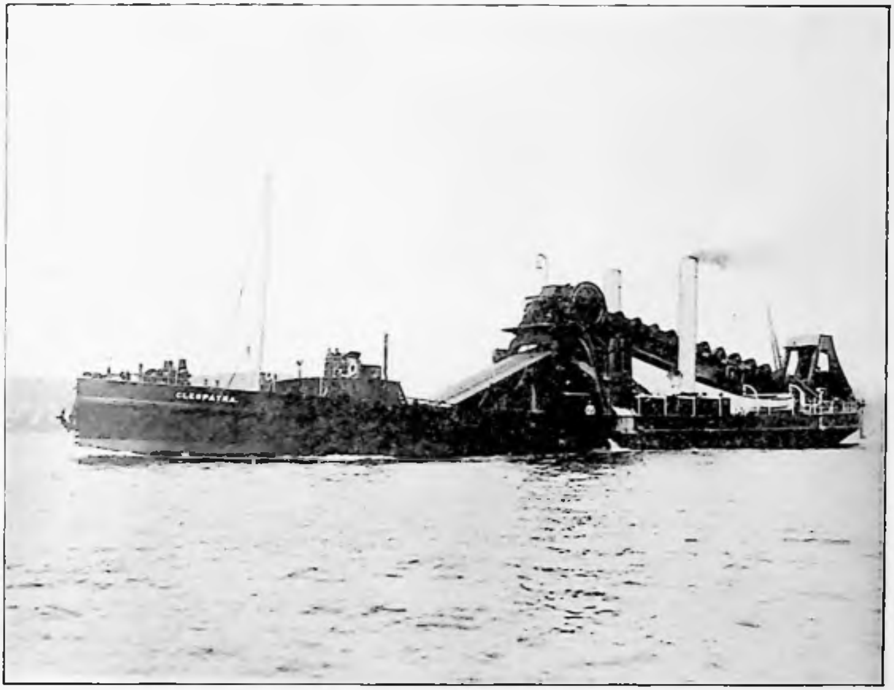
The dredger is to be equipped with three powerful winches for operating the mooring chains, two forward and one at the stern.

The kedge anchors are to be 15 cwts. each, the head and stern anchors 20 cwts. each, kedge chains $\frac{7}{8}$ inch diameter and stream chains $1\frac{1}{8}$ in. diameter.

The main gearing is to be of cast steel, machine moulded or machine cut, as may be necessary, and the power is to be transmitted from the engine by means of double belt drive or through friction clutch and steel gearing, as may be preferred.

The ladder hoisting engine and gear are to be of very ample power and strong construction, capable of raising the ladder from the lowest working depth until the bottom tumbler is out of the water in six minutes. It is to be controlled from a cabin placed on the deck of the dredger, from which the main engines and winches are also to be controlled by signal telegraph.

The buckets are to be built up of steel back castings having wrought steel body plates rivetted thereto and fitted with



Stern Well Bucket Dredger *Cleopatra*, built by Simons of Renfrew.

cutting lips of hardened manganese steel; the body plates and backs are to be perforated. The links are to be of solid forged mild steel, and the eyes of both links and buckets are to be fitted with hard high carbon steel bushes. The pins are to be of solid forged manganese steel, specially toughened.

The ladder rollers are to be of special deeply chilled cast iron fitted with wrought steel spindles having renewable sleeves working in renewable chilled cast iron half bushes.

The top and bottom tumblers are to be of specially toughened manganese steel, and the bottom tumbler is to be fitted with a long cast iron bush working on a turned steel shaft having special arrangements for the exclusion of dirt and grit from the bearings and means for forcing grease into the bearings.

The dredger to be supplied with electric lighting installation.

The hull, engines and boiler are to be built under special survey and classed 100 A1 at Lloyd's or the equivalent class in the Bureau Veritas or other approved registration society.

Conditions for Trials of Dredger.—

1. The dredger is to be capable of dredging in its own depth of water, cutting its own flotation and at any depth down to 70 feet below the water level.

2. The dredger is to be capable of raising and delivering into barges on either side not less than 500 tons of ballast gravel per hour when dredging at a maximum depth of 70 feet.

Two trials are to be made by filling into two 500 cubic yard hopper barges at the rate of 500 tons per hour.

The rate of dredging is to be computed by measuring the volume of material filled into the barges during a period of one hour into each barge.

The first barge is to be moored on the port side and the second is to be moored on the starboard side of the vessel.

3. The hinged shoots must be lowered and raised in 60 seconds.

4. When the ladder is raised to its highest position the bottom tumbler must be clear out of the water.

5. Each boiler is to be capable of independently working the dredger. To demonstrate this, the port boiler will be used to fill one barge and the starboard boiler to fill the other barge.

6. The ladder hoisting engine is to be able to raise the ladder in six minutes from the lowest working depth until the bottom tumbler is out of the water.

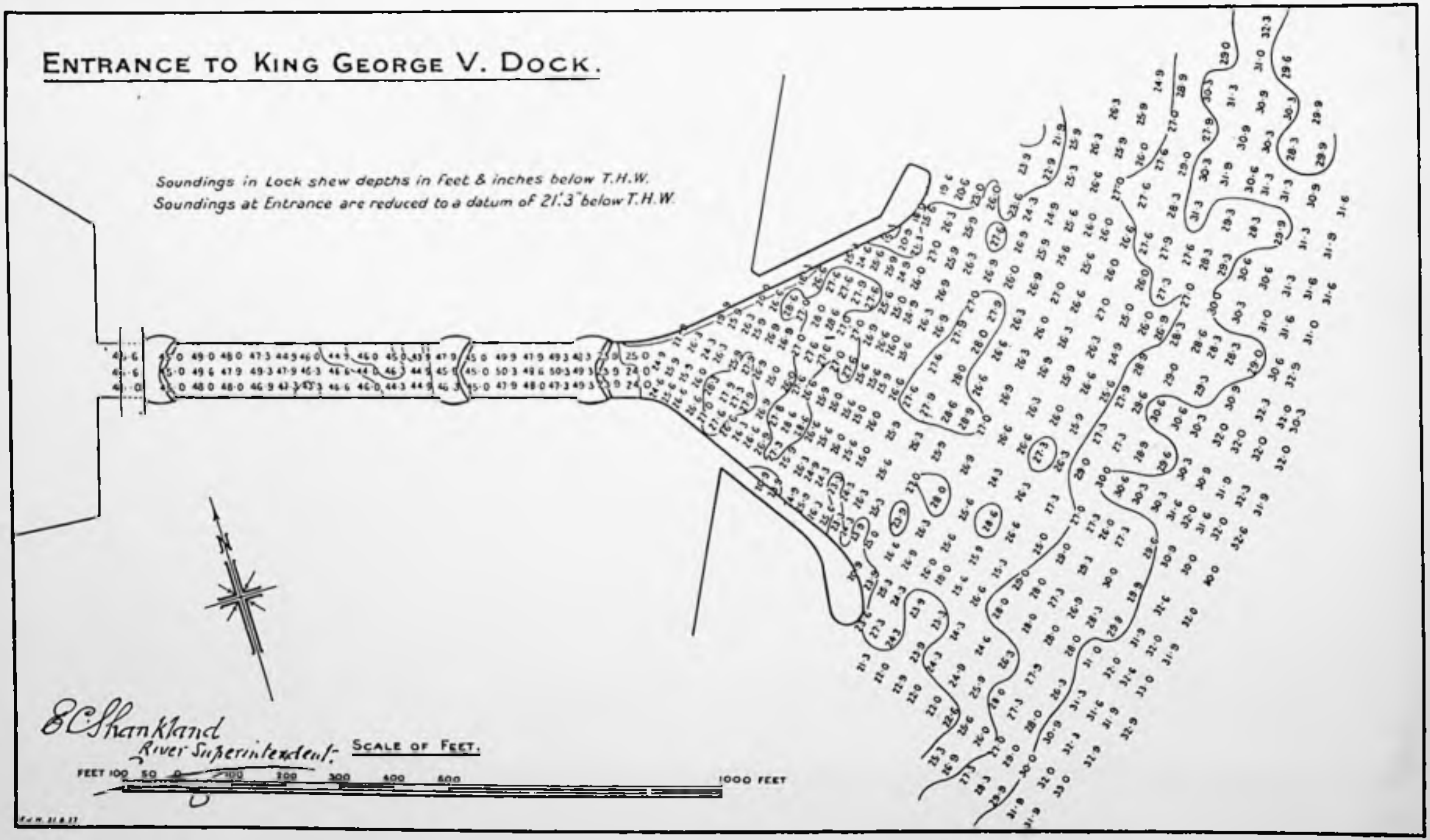
The ladder is to be hoisted right up and lowered on to the beam over the well at the end of each trial.

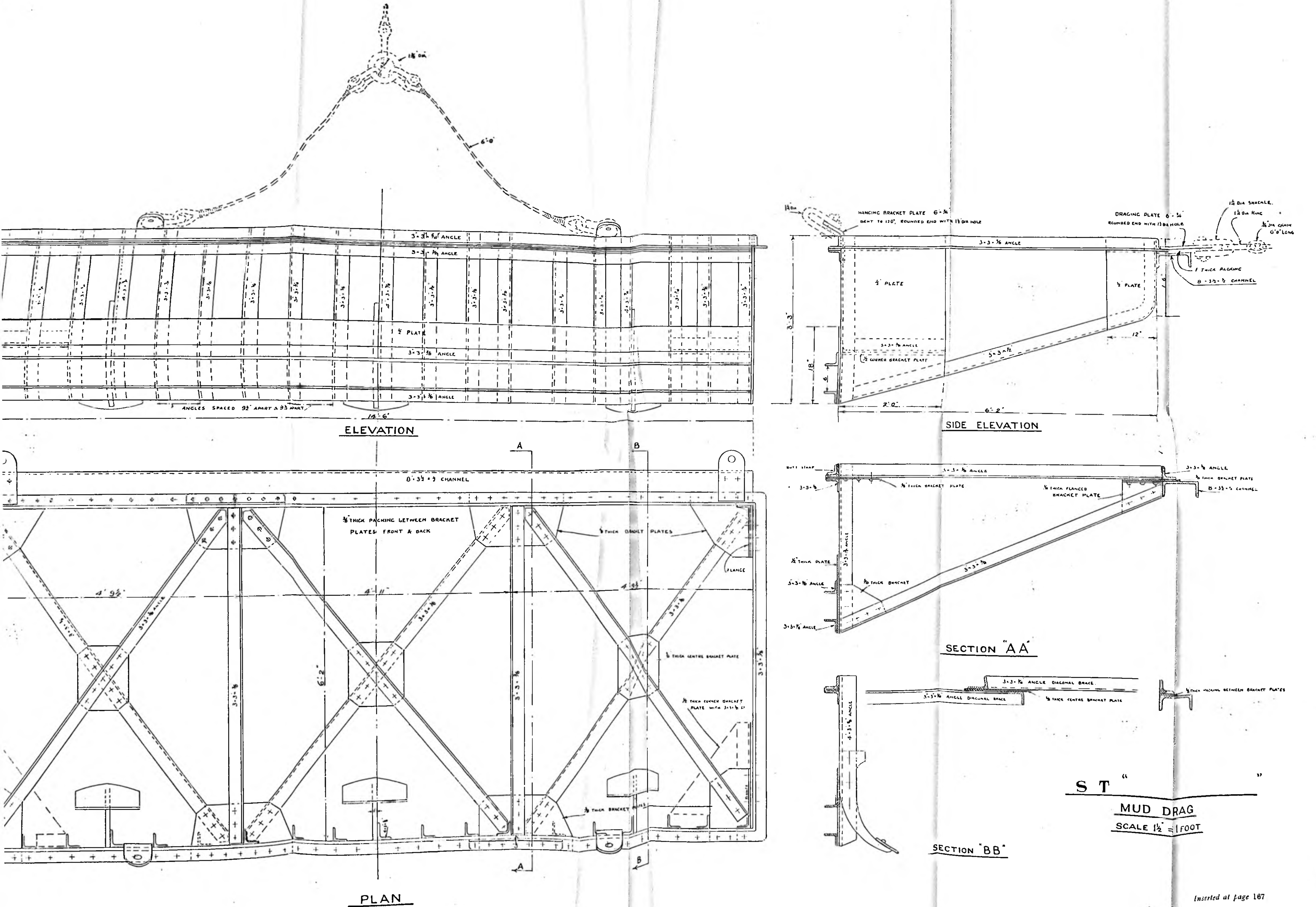
Drags and Eroders for Maintenance of Dock Entrances and Small Channels.

Owing to the necessity of situation for dock entrances (*e.g.* being situated in a slack tide) their approaches frequently call for attention by dredger. It usually occurs that the occasions on which a dredger can float and operate at the entrances, they are, for tidal reasons, also utilised for shipping entering or leaving the dock system.

Drag at Stern of Tug.

Under these conditions the dredger is very much in the way even when hove clear of the entrance and lying alongside the pierhead to allow ships to dock and undock—the tugs being deprived of manoeuvring space by the presence of dredger


ENTRANCE TO KING GEORGE V. DOCK.
Soundings in Lock shew depths in Feet & inches below T.H.W.
Soundings at Entrance are reduced to a datum of 21'.3" below T.H.W.
N
E C Shankland
River Superintendent.
SCALE OF FEET.
FEET 100 50 0 100 200 300 400 600 1000 FEET



Inserted at page 167

chains, etc. The dredger is, moreover, the subject of enforced idleness if not self-propelled and employed at such times in depositing the load.

Such delays therefore mean expense and loss of time. Consequently, in certain ports, it becomes necessary to consider a plan to improve on the previous method of dredging with its unavoidable delays. Experiments were made and proved successful with a drag similar to a road harrow as shewn on page 166. The dimensions and detail are shewn in Appendix. A tug of 600 i.h.p. was utilised to operate the drag.

The teeth are sufficiently long to bite into an incrustation or to remove debris such as wire or small jetsam. Dragging is usually confined to the first quarter of the ebb tide in order to give the silt an opportunity to be carried down stream.

Critics of the principle of thus maintaining a dock entrance may voice the view that entire removal of the silt is not effected but merely transposed to a situation in proximity to the entrance. The answer to this viewpoint is that the silt is merely returned to the channel or river bed from whence it came. No case, therefore, against conservancy can be made.

Not only has dragging proved a saving of time to the dredger now employed elsewhere, but the costs of removal in hopper which cost may be as much as on a ratio of 3·5 to 1 per cube yard when compared with raising are saved.

We shew herewith in illustration a plan of the dock entrance so maintained and photographs of a barge channel similarly treated (see facing pages 166 and 168).

It was considered inadvisable to dredge this large channel as its situation at the foot of a river bank rendered precautions against slipping necessary.

Blowers and Eroders.—The principle of a "blower" or hydraulic jet has, under certain specific conditions, something to recommend it. By operating the jet continuously about 1 foot above mud level the area under treatment is maintained in a state of flocculent activity and the mud kept in a state of suspension.

For the method to be a success, therefore, constant treatment is essential which may or may not be justified if the depth thus maintained is operated at a lower cost than by dredging or raking by drag.

Both dragging and blowing by hydraulic jet are limited in use to certain situations. Blowing is also of service in keeping aprons of dock sills, the hinges and mitre rollers free of mud.

From Bridge looking West.

From Bridge looking East.

From Barge Gateway looking East.

SHALLOW BARGE CHANNEL MAINTAINED BY DRAG.

CHAPTER V.

Valuation of Plant—Insurance—Rates for Charter and Hire—Costing of Estimating Dredging Operations—Cubic Areas and Weight of Materials—Bulking and its Effects—Delays which Affect Costs—Towing—Use of Explosives to Assist Dredging—Rock Removal—Sweeping after Blasting or Rock Breaking to Ensure Navigable Depth—Splicing and Socketing of Wire Ropes.

Valuation of Plant.—When considering dredging estimates the valuation of the plant to be employed forms one of the first items in the costing. The type of dredger may be of high capital value but inexpensive to operate; conversely, it may be of low capital value but expensive to operate. The plant may have to be built for the operation or it may be in existence. If the plant is old and has depreciated, replacement is a consideration. No dredging company or public authority can observe the gradual depreciation of plant without provision for ultimate replacement. This replacement may be of a progressive nature and the new dredgers of improved and more expensive type.

Regarding depreciation of dredging plant, it is the custom in merchant shipping of the cargo type to depreciate the value of the hull and machinery at the ratio of 4 per cent. or 4½ per cent. per annum on building cost.

So that after approximately 25 years every £100 can be regarded as having been exhausted in used tonnage. After that period it becomes necessary to survey the property and to

value it in a different light. It is either an asset or a liability. If in use as a profit earning unit it will be an asset and possess an insured value. The difference between dredging and cargo vessels, however, is this: Dredging machinery requires frequent replacement so that comparisons should include this fact. Insured values and/or risks are affected by the conditions under which the dredger is working. The vessel may be of high capital value and working in positions of utmost safety. Under these conditions there is no great need for any but a light insurance; applying these general principles to dredging plant the matter requires special treatment because so much of the material of a dredger consists of replaceable machinery—buckets, rollers, pins, links, purchases, etc.

If the dredger has been well maintained, there may be little of the original structure other than boilers, engines, and hull which has not been renewed in the course of the dredging life.

In any case, the point to be decided is whether the vessel is an asset or a liability after a period of usage. If an asset, then to what extent should the vessel be regarded as such.

During the 15 years through which Europe has passed the economic conditions and values have changed, and these changes have affected the values of vessels built before the war to a considerable extent.

Vessels of pre-war build may be entitled to several different values:

(1) Original cost depreciated at 4 per cent.
(2) Cost if built in 1918 (when prices were much higher) 4 per cent. for same depreciated period as (1).
(3) Replacement value at present day costs of building.
(4) Market value.

It is interesting to note how these values work out for the purposes of considering insurance of the vessels.

We show also a valuation of a dredging fleet for the purpose of hire and/or charter, based on similar lines of replacement and original cost depreciated over a period of time.

SUGGESTED ALTERNATIVE RATES FOR SHORT PERIOD HIRE OF DREDGERS AND GRABS.

	Dredger *Scylla*	Dredger *Chary-ibdis*	Dredger *Tetuan*	Grab Hopper *Octopus*	Grab *Gudgeon*
	£	£	£	£	£
1.—Original cost	22,353 (1911)	22,353 (1911)	7771 (1884)	21,943 (1911-24)	2298
Estimated cost of replacement at June, 1914	22,500	22,500	8,000	19,412	2,300
Replacement + 70 per cent. on original cost	38,250	38,250	13,600	33,000	3,910
Present value at 4% depreciation	20,735	20,735	2449	20,735	796
Proposed rate of hire being 20% of present depreciated value of craft:					
per annum	4147	4147	489	4147	159
per week	80	80	10	80	4
2.—Capital cost	£22,353	22,353	7,771	22,977	2298
Interest 4 %	894	894	311	919	92
Sinking fund 3%—25 years	613	613	213	630	63
Establishment (say) 5%	1118	1118	389	1149	115
Conditioning and drydocking	500	500	500	500	500
Profit (say) 5%	1118	1118	389	1149	115
Total	£4243	£4243	£1802	£4347	£885
Proposed rate of hire per week	£ 82	£ 82	£ 35	£ 86	£ 18

Costs and Costing of Dredging Operations.—Simple estimating for operations consists of the use of known factors to arrive at the cost of a particular piece of work. It should be exclusive of interest on capital and depreciation of plant or any special overhead charges which may be applied if required but when applied might be then termed proper estimating.

Here is a simple estimate of an extremely difficult excavation. Bucket dredger working in conjunction with self-propelled hoppers.

Cubic Yards to be removed (with allowance for bulking) 17,800 Cubic Yards Stiff Clay

Dredger *Excavator*	No of days	Rate per day	Amount	Cost per cubic yard
Raising Operation				
Dredger employed	17	£45	£765 0 0	
Tug *Dart* shifting m'rings	1¼	£24	30 0 0	
Tug *West* ,,	1⅓	£24	32 0 0	
Steam launch attendance	¾	£20	15 0 0	
			£842 0 0	0s 11·35d.
Conveyance to sea and return distance 132 miles (statute)				
Hopper *B*	13½	£31	£418 10 0	
,, *C*	3½	£40	140 0 0	
,, *K*	12	£38	456 0 0	
,, *L*	15	£40	620 0 0	
Steam launch attendance	¾	£20	15 0 0	
			£1649 10 0	1s 10·24d
			£2491 10 0	2s 9·59d

The detail of the above estimate is shewn on p. 173, and it should be noted that the dredging period contains time during which work required to be suspended for the removal of moorings and for a holiday period at Christmas.

Vessels employed	Period of Working													
	October.											Dys	Est. cost per day	Totals
	12	13	15	16	17	18	20	22	23	24	25			
(*A*)													£	£
Dredger *Excavator*	½	1	1	1	1	1	1	1	1	1	½	11	45	495 0
Hopper *B*	½	1	1	1	1	1	1	1	1	1	—	10½	31	325 10
,, *K*	—	1	1	1	1	1	1	1	1	1	—	10	38	380 0
,, *L*	—	—	—	—	—		—	—	—	—	½	10½	40	420 0
Tug *West*	¼	1/12	1/12	1/12	⅓	1/12	⅙	1/12	—	—	1/12	1⅙	24	28 0
Steam launch	—	—	—	—	—	—	—	—	—	—	—	1	20	20 0
														1668 10
	December					January								
	23	27	28	29	31	1								
(*B*)	shift													£
Dredger *Excavator*	1	1	1	1	1	1	—	—	—	—	—	6	45	270 0
Hopper *B*	—	1	1	1	—	—	—	—	—	—	—	3	31	93 0
,, *C*	—	—	½	1	1	1	—	—	—	—	—	3½	40	140 0
,, *K*	—	—	½	1	½	—	—	—	—	—	—	2	38	76 0
,, *L*	—	1	1	1	1	1	—	—	—	—	—	5	40	200 0
Tug *Dart*	1	¼	—	—	—	—	—	—	—	—	—	1¼	24	30 0
Steam launch	—	—	—	—	—	—	—	—	—	—	—	½	20	10 0
Tug *West*	—	—	½	—	—	½	—	—	—	—	—	6	24	4 0
														823 0

17,800 cubic yards—at 2s. 9½d. per cubic yard = £2491 10

EVALUATION FROM 12 MONTHS PREVIOUS WORKING WITH FACTORS FOR PRESENT CONDITIONS APPLIED.

Estimated cost for 12 months	Dredger *Excavator*	Hopper *B*	*C*	*K*	*L*
Working expenses -	£6691	6751	6062	6062	6062
Maintenance of plant exs.	£5922	1980	5280	4520	5280
	£12,583	£8731	£11,342	£10,582	£11,342

Effective days per annum		=282
Deductions	Sundays	52
	Bank Holidays	4
	Christmas Day	1
	Good Friday	1
	King's Birthday	1
	Repairs	24
	365 — 83=282	

Cost per day per unit					annual cost / 282
Dredger *Excavator*		£44	12	5	say £45
Hoppers	*B*	30	19	3	31
	C	40	4	5	40
	K	37	14	0	38
	L	40	4	0	40
Tug *Dart*					24
West					24
Steam launch					20

Simple estimating to determine cost of hopperage only when depositing approx. 10,000 cubic yards in close proximity to area being dredged. The estimate is on a weekly basis.

(Note.—Low cost per cubic yard for depositing.)

HOPPER XL. 650 Cubic Yards.

	per week		
Wages	£43	10	0
Stores	5	0	0
Coal 15 tons at 19s. 6d. per ton	18	17	6
Insurance	6	0	0
Sundries	1	0	0
Maintenance	20	0	0
	£94	7	6

Removal on basis of 3 loads every 2 tides.

$$\frac{650\times3\times10}{2}=9750 \text{ cubic yards per week.}$$

2·30d. per cubic yard.

ALTERNATIVE BASIS—COST OF DREDGING

Work Scheme.

To be dredged and pumped	5,500,000 c.y.
To be dredged and pumped	1,500,000 c.y.
measured *in situ* total	7,000,000 c.y.
in means of conveyance	8,750,000 c.y.
Average distance to dumping place -,	2000 c.y.
Average distance to pumping place - -	1000 y. 1000 y.

To be executed in 3 years.
250 workable days of 10 hours per year.
Nature of soil soft clay and mud.

Required Plant

1 bucket dredger daily output	3000 c.y.
1 bucket dredger daily output	3600 c.y.
1 hopper clay-cutter output	7200 c.y.
1 suction dredger for pumping	7000 c.y.
5 tugboats of 150 H.P. to H.P.	
8 mud barges contents -	300 c.y.

Necessary pipe-line and further auxiliary plant.

Specification of Unit Price.

Cost of transport - - - -	15	per cent.
Depreciation of plant - - - -	31	,,
Insurance during execution - -	4	,,
Wages of dredging staff - - -	8	,,
Consumption of coal - - - -	21	,,
Grease, oil, etc. - - - - -	2	,,
Maintenance of plant - - - -	4	,,
Repairs of plant - - - - -	10	,,
Sundries - - - - - -	5	,,
Total unit price -	100	,,

CALCULATION OF A BUCKET DREDGER.

To dredge per hour 500 cubic metres sand of a specific gravity of 1·8 to 2·0 at a depth of 14 meters.

Contents of Buckets.

$$I = \frac{Q}{\eta \cdot 60 \cdot \frac{v}{21}}$$

I = contents of a bucket in cubic metres.

Q = output of dredger per hour = 500 M^3.
n = degree of admission of the buckets
For sand 0·6 to 0·8
For clay and mud 0·8 to 0·9
v = speed of bucket chain = 23 M/min.
l = length of bucket links = 0·8 M.
$\frac{v}{21}$ = number of buckets raised per min.
I = 0·800 cubic metres

Power of Driving Engine.

$$N_i = \frac{[Q(\gamma_1 - \gamma_2)\ t.\ 1000 + Q\gamma^2\ h.\ \ 1000.].\ L.}{60 \times 60 \times 75.}$$

$$N^i = \frac{Q}{270} \cdot L \cdot (\gamma_1 - \gamma_2)\ t. + \gamma_1\ h.)$$

N^i = required power in I.H.P.
γ_1 = specific gravity soil = 2·00
γ_2 = specific gravity of water = 1·02
t = maximum depth to be dredged = 14 M.
h = height of the axis of upper tumbler above water = 9 M.
L = proportion of initial power to running power = 3·8
For sand 4 to 3·5
For clay and mud 3
N^i = 2·30 I.P.K.
To be added 50 per cent for driving winches total N^i = 350 I.P.K.

Heating surface 0·34 M^2 per I.H.P.	= 120 square metres
Displacement (L B – L'B') T. $\delta \cdot \gamma_2$.	= 908 tons
Total weight of dredger - -	= 809 tons
Ballast - - - - - - - - -	= 99 tons

DECK JOURNAL OF DREDGER .... work

DATE 193	TIME EMPLOYED						LENGTH OF													
	Com-menced Work	LOADING				Finished Work	Loading		DELAYS (Give Times in "											
		Began	Interrupt'd		Complet'd				Bad Weather		Shifting Chains		Changing Links and Pins		Traffic					
			From	To			H.	M.	H.	M.	H.	M.	H.	M.	H.	M.	H.			
	Total for Week, or carried forward																			

…ng at …… *Week ended Wednesday,* …… *193* ……

…IE (…arks" Column)										Total Time		MATERIAL DREDGED		Hopper No.	Site Dredged	Particulars of Wind and Weather and General Remarks (Giving Times)
…of …ers		Machinery		Swinging Hoppers		Other Causes						Nature of	Quantity Cu. Yds.			
…	M.	H.	M.	H.	M.	H.	M.			H.	M.					

(Signature) …… *Master*

To face page 174.

CALCULATION OF A CLAY CUTTER.

To be dredged 500 M^3. hard clay per hour at a depth of 14 metres.

To be pumped through a floating pipe-line, 1400 metres length.

Maximum height of pipe-line 6 meters above the water-level.

The dredged material is also to be sucked from barges alongside and to be pumped ashore.

CAPACITY OF SUCTION PIPE.

Specific Gravity.

$$\gamma = \frac{\gamma_1 + n\gamma_2}{1+n} = 1{\cdot}14.$$

γ = specific gravity of mixture
γ_1 = specific gravity of clay = 1·8
γ_2 is specific gravity of water = 1 –
n = proportion water to clay in mixture = 5

Diameter of Suction Tube.

$$q = \frac{\pi\, d^2{}_s v_s}{4}$$

$$d^s = 2\sqrt{\frac{q}{\pi v^s}} = 0{\cdot}655 \text{ M.}$$

d^s = diameter suction tube
v_s = velocity of mixture in suction tube to be 2·5 to 3·5 m/sec. say: 2·5 m/sec.

Pumping Height.

$$H = h_d + \frac{l}{100}p. = 27 \text{ M.}$$

H = pumping height
h^d = maximum height pipe-line above water = 6 M.
l = length of pipe-line = 1400 M.
p = loss of pressure per 100 M. pipe-line
For soft soil = 0·13
For hard clay = 0·15
For gravel and sand = 0·18

Diameter of Pump.

$$H = \frac{v^2}{c}$$

v = $\sqrt{H.\,c.}$ = 22 m/sec.
v = peripheral speed of centrifugal pump
c = for heavy material = 22 for soft material = 18

$$D = \frac{60{\cdot}v.}{\pi.n.} = 2{,}3 \text{ M.}$$

D = diameter of pump
n = revolutions of pump per min. = 185

Suction Height.

$$h^s = t\,(\gamma - \gamma^2) + h.\,\gamma. = 3{\cdot}1 \text{ M.}$$

h^s = suction height.
t = depth of dredging = 14 M.
h = height suction tube above water level = 1 M.

Diameter of Pumping Tube.

$$d^p = 2\sqrt{\frac{q}{\pi.\,v^p}}\ 0{\cdot}60 \text{ M.}$$

d^p = diameter pumping tube
v_p = velocity of mixture at mouth of pipe line to be 2 to 3 m/sec. say: 3 m/sec.

WIDTH OF PUMP.

$$b = \frac{q}{(d\pi. - z.e).v_e} = 0{\cdot}41$$

b = width of pump
d = diameter of inlet pipe = 0·75
z = number of wings = 4
v_e = velocity of mixture at entrance = 1·05
e = width of a wing = 0·10

$$q = \frac{(n+1)\,Q.}{60 \times 60} = 0{\cdot}84 \text{ m/sec.}$$

q = output mixture raised per sec
Q = required output per hour = 500 M^3.

SUMMARY OF COSTS OF VESSELS ATTACHED

Type of vessel	Dimensions	Engines	Fuel used and contract price per gallon		Total hours under-way
				s. d.	Hours
Motor launch	24′ long 5′ 6″ beam, moulded 2′ 8″ depth 1′ 8″ draft	4 cyl. Kelvin Rated 12 B.H.P.	Start petrol Runs on A.V.O.*	1 $6\frac{1}{2}$ $8\frac{1}{2}$	1457
,, ,,	24′ long 6′ beam, moulded 2′ 8″ deep 1′ 9″ draft	Gleniffer Rated 14/16 B.H.P.	Start petrol Runs on A.V.O.	1 $6\frac{1}{2}$ $8\frac{1}{2}$	1497
Motor drifter	78′ long 18′ beam 7′ 6″ mean draft	2 cyl. Bolinder Rated 80 B.H.P.	Gas oil	$4\frac{7}{8}$	473
,, ,,	78′ long 18′ beam 7′ 6″ mean draft	2 cyl. Bolinder Rated 80 B.H.P.	Gas oil	$4\frac{1}{8}$	428

* Anglo-American vapourising

Economics of Motor Launches, Steam Launches and Motor Vessels.—In costing up dredging services, the expense of the auxiliary craft used for transporting labour, running stores and in general attendance forms an important matter.

We present here a typical return of the performance and running costs of two small motor launches, two sea-going motor (semi-Diesel) vessels which were capable of carrying stores and of undertaking light towage, and also a comparative detailed cost of a steam launch of 9 to 10 knots speed parallel with a motor launch of 14 to 15 knots speed—when in full efficiency service. It will be noted that the greater mobility of the faster motor launch tends to raise the fuel bill, which must be controlled if the relation of economy is to be maintained.

TO DREDGING AND GENERAL SERVICE TAKEN OVER 23 WEEKS.

Amount fuel used	Estimated miles per gallon (Cruising speed)	Estimated mileage for period	Costs: Total, inc. wages, stores, fuel and insurance	Costs: Fuel and oil only	Costs per mile: Total (excluding maintenance)	Costs per mile: Fuel only	Remarks	Working pers'nnel
Galls.	Miles	Miles	£	£	d.	d.		
754	6	4524	126	34	6·6	1·8		1
							Add 1d. per mile for maintenance	
754	6	4524	161	34	8·5	1·8		1
1213	3	3639	477	23	31·4	1·5	Add 1d. per mile for maintenance	4
1116	3	3348	475	32	34·0	2·3	Add 1d. per mile for maintenance	4

ECONOMICS OF MOTOR STEAM LAUNCHES.

Steam launch built 1910
Original cost £4500
Replacement costs £6100

Crew*			
1	Skipper	79/-	per week
1	Deckhand	71/6	,,
1	Boy	25/-	,,
1	Engineer	74/6	,,
1	Stoker	57/-	,,
1	Watchman	61/-	,,

Cost (Annual)

	£	s.	d.
Wages (with overtime) -	£1018	0	0
Clothing and stores -	155	0	0
Coal and oil - - - -	270	0	0
Insurance, Health and Nat. Insurance - -	64	0	0
Incidentals - - -	17	0	0
Maintenance - - -	552	0	0
	£2076	0	0

Speed 9-10 knots.

Motor launch built 1928
Cost £2000

Crew*			
1	Skipper	81/-	per week
1	Deckhand	71/6	,,
1	Driver	74/6	,,
1	Watchman	61/-	

Cost (Annual)

	£	s.	d.
Wages Skipper	£210	12	0
Deckhand -	195	0	0
Driver - -	213	0	0
Watchman -	158	12	0
Clothing and stores	150	0	0
Overtime - -	52	0	0
Fuel petrol 110 H.P. 1030 galls. per month, say 10,000 galls. per annum at 1/6 per gall. -	750	0	0
Say 360 galls oil - -	70	10	0
Insurance on £2000 -	34	0	0
Maintenance - - -	120	0	0
Incidentals - - -	26	0	0
	£1978	18	0

Speed 14-15 knots.

* Slightly variable.

MAINTENANCE PROGRAMME—DREDGING SERVICE—BASED ON ANNUAL OUTPUT.

ESTIMATE OF OPERATING EXPENSES FOR 6 MONTHS—SUMMER PERIOD.

	Wages	Stores and m'erials	Coal and coke	Expense	Insur-ance	Totals	
						Unit	Class
	£	£	£	£	£	£	£
Dredgers—Bucket.							
No. 1. (Laid off)	218	7	—	20	127	372	
No. 2. (Single shift)	1440	246	962	40	197	2885	
No. 3. (Double shift)	1918	360	1140	40	196	30,217	
				26,563	196		
No. 4. ,,	2818	400	3000	65	417	6700	
No. 5. ,,	2818	400	2200	65	417	5900	
No. 6. (Single shift)	1548	295	731	35	349	2958	
No. 7. (Double shift)	2043	230	1320	65	241	3899	
No. 8. (Single shift)	874	88	211	5	250	8640	
				7437			
No. 9. (Laid off)	26	2	5	—	3	36	61,607
Dredgers—Grab.							
No. A. Raising	387	43	120	5	7		
Removing	234			120		916	
No. B. Raising	315	41	55	5	19		
Removing by contract				1250		1685	
No. C. Raising	237	18	59	3	2		
Removing by contract				1250		1569	4170
Hoppers—Class "B"— Self-propelled.							
No. 3. Conveyor	1293	230	1300	—	126	2949	
No. 4. ,,	1293	230	1300	—	126	2949	
No. 5. ,,	1293	230	1300	—	126	2949	
No. 6. ,,	1293	230	1300	—	126	2949	
No. 7. ,,	1293	230	1300	—	126	2949	
No. 8. ,,	1293	230	1300	—	126	2949	17 694
Hoppers—Class "C"—							
No. 9. Conveyer	1203	210	1235	—	131	2779	
No. 10. ,, (Laid off)	26	3	—	—	65	94	
No. 11. ,,	1203	210	1235	—	131	2779	
No. 12. ,,	1203	210	1235	—	131	2779	
No. 13. ,,	1203	210	1235	—	131	2779	
No. 15. ,,	1203	210	1235	—	131	2779	13,989
Carried forward	£28,675	4563	23,778	36,968	3476	97,460	97,460

(.. *Section*)

Engine Room Journal of Vessel..............................

for week ended Wednesday.............................. 19.....

Date		No. of Trips or Loads	TIME RUNNING				Revs. per Min.	Gear Used	Boiler Pressure	GAUGES				TEMPERATURES				Den... B...
			From	To	Total					H.P.	M.P.	L.P.	Vacuum	Hotwell	Feed	Sea	Dis-charge	P.
					H.	M.												
1	2	3	4	5	6		7	8	9	10	11	12	13	14	15	16	17	18

Total Time Running	
Total No. of:—	
(A) Trips	
(B) Loads	

STORES	Engine Oil	Cylinder Oil	Stern Tube Oil	Paraffin Oil	Castor Oil	Colza Oil	Grease	
							Tumbler	Win...
	Galls.	Galls.	Galls.	Galls.	Galls.	Galls.	lbs.	lbs.
On hand								
Received during week								
TOTAL..								
Remaining								
Used during week ..								

INSTRUCTIONS.

I. A record is to be made (*a*) on Hopper Barges for each outward and inward trip.
(*b*) on Dredgers for each Hopper loaded.
(*c*) on Tugs and Launches for each Shift.

II. Column 3 applies to Dredgers and Hoppers only, and column 8 to Bucket Dredgers only.

III. In column 25 are to be inserted (*a*) any breakdown or special incident with Time and Cause.
(*b*) any adjustments and/or Repairs made by Engine Room Staff.

COAL					Weight of Ashes		REMARKS
Kind received	Quality	Quantity Tons	Cwts.	Indent No.	Tons	Cwts.	
20	21	2	2	23	2	4	25
Total Coal Received							

Date		
In Bunkers at commencement		
TOTAL		
Date		
In Bunkers at close of week		
Coal consumed for week ..		

______________________ *Engineer* (______)

______________________ 19____

MAINTENANCE PROGRAMME—DREDGING SERVICE—BASED ON ANNUAL OUTPUT—*Continued.*

ESTIMATE OF OPERATING EXPENSES FOR 6 MONTHS—SUMMER PERIOD.

	Wages	Stores and m'erial	Coal and coke	Expenses	Insurance	Totals	
						Unit	Class
	£	£	£	£	£	£	£
Brought forward	28,675	4563	23 778	36 968	3476	97,460	97,460
Hoppers—							
No. 16. Conveyor	1507	250	1690	—	195	3642	
No. 17. ,,	1507	250	1690	—	195	3642	
No. 19. ,,	1507	250	1690	—	195	3642	
No. 21. ,,	1507	250	1690	—	195	3642	
No. 23. ,,	1507	250	1690	—	195	3642	18,210
No. 24. ,,	1507	250	2080	—	352	4189	
No. 25. ,,	1507	250	2080	—	352	4189	
No. 26. ,,	1507	250	2080	—	352	4189	12,567
Blower—							
Wildbore (Double shift)	762	40	147	—	8	957	957
Drags—							
Killick (Double shift)	762	40	155	—	36	993	
Standard (Single Shift)	420	30	98	—	36	584	1577
Tugs and Launches.—							
Dart	966	161	743	—	96	1966	
West	966	161	743	—	96	1966	
Ems	267	34	80	—	15	396	
Raven	818	70	528	—	49	1465	5793
Grab-hopper dredger							
Octopus (Double shift)	1634	255	1560	—	213	3662	3662
Spoon dredger (Canal	120	10	—	—	—	130	130
Extra leave for Officers and other contingencies	550	—	—	—	—	550	550
	£74,996	7364	42,522	36,968	6056	140,906	140,906

N.B.—Foregoing estimate includes operations differing considerably in character, viz.—

(1) Raising in docks by bucket dredger—conveyance, average distance, 60 miles to sea (120 miles double run by contract). Dumb hoppers towed by tugs.

(2) Raising in river by bucket dredger—conveyance to sea in self-propelled hopper (approx. 60 miles to deposit site).

(3) Grab dredging in docks and depositing on land.

(4) Grab dredging in river and depositing for reparation of embankments on land.

(5) Dragging and blowing mud for clearance of dock entrances.

(6) Spoon and bag (scavenging canal) dredging.

(7) Grab hopper dredger working river and docks carrying and depositing own load.

Bulking of Dredgings.

There is no part of dredging operations fraught with more uncertainty in breaking new ground than the probable bulking of materials.

In place of dredging let us consider coal packed in a seam under pressure, 1 ton of which may measure when so packed less than 40 cubic feet. When it is broken out with the pickaxe or excavating tool we find that it measures considerably more than 40 cubic feet, probably 45 cubic feet to the ton of 20 cwts. And so it is with dredgings. *In situ* the cubic measurement is as a rule considerably less than when broken out and raised for disposal.

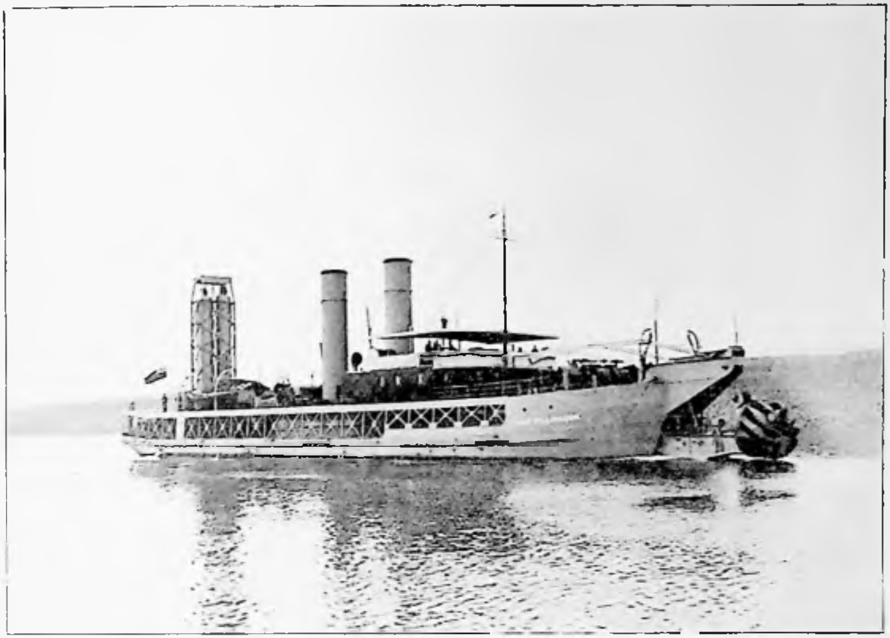
This alteration in the dimensional and weight factors is termed "bulking," which with the unavoidable moisture contents is that which requires to be disposed of.

Our illustration on page 124 shews the bulking of conglomerate found in Halfway Reach in the Thames. Explosives were necessary to break up this material, which lay in slabs measuring 5 feet thick and 30 to 40 feet in length and width.

TABLE SHEWING APPROXIMATE HOURLY DREDGING CAPACITIES OF BUCKET DREDGERS WORKING IN ORDINARY FREE MATERIAL.

Bucket Capacity		Practical Dredging Capacity per hour			Bucket Capacity		Practical Dredging Capacity per hour		
Cubic Feet	Litres	Tons at 20 c.f. per Ton	Cubic Yards	Cubic Metres	Cubic Feet	Litres	Tons at 20 c.f. per ton	Cubic Yards	Cubic Metres
5	142	216	160	122	21	594	810	600	457
6	170	256	190	145	22	622	837	620	471
7	198	283	210	160	23	650	864	640	488
8	226	324	240	183	24	680	891	660	504
9	255	364	270	206	25	708	918	680	520
10	283	405	300	229	26	736	958	710	543
11	311	432	320	244	27	764	999	740	564
12	340	472	350	268	28	793	1026	760	580
13	368	513	380	290	29	821	1053	780	596
14	396	553	410	314	30	849	1080	800	612
15	424	580	430	329	31	877	1107	820	626
16	452	621	460	352	32	904	1134	840	640
17	482	661	490	374	33	933	1161	860	656
18	510	702	520	397	34	964	1188	880	672
19	538	729	540	413	35	991	1215	900	688
20	566	769	570	436	36	1019	1242	920	704

NOTE.—Above Table is based on 75 per cent. of full capacity of buckets working at speeds ranging from 19 per minute for smallest sizes to 15 per minute for largest sizes.



The Suction Cutter *Lord Willingdon*, for Indian Harbour Dredging.
One of the more recent types built by Simons of Renfrew.

A Suction Pipe Ladder with 24-inch Cutter. Lobnitz Ltd. of Renfrew.

It therefore requires care and local knowledge to estimate the relation between cubic yards *in situ* as measured from the chart or plan and the requisite conversion factor for bulking the same dredgings as removed by hopper.

The table below, showing bulk of subaqueous soils, etc., gives a fair rule for bulking.

BULK OF SUBAQUEOUS SOILS, ETC.

Approximate Weight in Tons per 100 Cubic Yards of Hopper Space Occupied after Dredging.

	Tons		
Sand (heavy)	153	=	17·6 c.f. per ton
Sand (light)	145	=	18·6 ,,
Sand and clay	150	=	18 ,,
Clay (soft)	138	=	19·5 ,,
Clay (boulder	145	=	18·6 ,,
Peaty soil	75	=	36 ,,
Gravel	150	=	18 ,,
Mud	126	=	21·4 ,,
Fine silt	100	=	27 ,,
Sandstone (as broken for bucket dredging)	150	=	18 ,,
Granite ,, ,,	157	=	17·2 ,,

EQUIVALENT OF ADMIRALTY KNOTS IN STATUTE MILES AND KILOMETRES.

(For use in estimating haulage to sea.)

Knots	5	5½	6	6½	7	7½	8	8½
Miles	5·75	6·33	6·90	7·48	8·06	8·63	9·21	9·78
Kilometres	9·26	10·19	11·12	12·04	12·97	13·90	14·82	15·75
Knots	9	9½	10	10½	11	11½	12	13
Miles	10·36	10·93	11·51	12·09	12·66	13·24	13·8	14·96
Kilometres	16·68	17·60	19·53	19·45	20·38	21·31	22·23	24·09

NEAR EQUIVALENTS OF CUBIC METRES IN CUBIC YARDS.

And Conversion into Tons D.W. at 20 c.f. per Ton.

Cubic metres	100	110	120	130	140	150	160	170	180	190	200
Cubic yards	130	143	157	170	183	196	209	222	235	248	261
Tons D.W.	176	194	212	229	246	264	281	299	317	335	353
Cubic metres	210	220	230	240	250	260	270	280	290	300	310
Cubic yards	274	287	300	313	326	339	352	365	388	391	404
Tons D.W.	370	388	405	423	440	458	475	493	510	529	547
Cubic metres	320	330	340	350	360	370	380	390	400	410	420
Cubic yards	417	430	443	456	469	482	495	508	523	536	548
Tons D.W.	564	582	599	617	634	652	669	687	704	722	740
Cubic metres	430	440	450	460	470	480	490	500	510	520	530
Cubic yards	561	574	587	600	613	626	639	652	665	678	692
Tons D.W.	757	775	792	810	827	846	863	881	898	916	933
Cubic metres	540	550	600	650	700	750	800	850	900	950	1000
Cubic yards	705	718	782	847	912	979	1046	1111	1174	1240	1304
Tons D.W.	950	968	1058	1146	1234	1321	1408	1497	1584	1673	1762

EQUIVALENTS OF LINEAL FEET IN METRES.

Feet	5½	6	6½	7	7½	8	8½	9	9½	10
Metres	1·67	1·82	1·98	2·13	2·28	2·43	2·59	2·74	2·89	3·048
Feet	11	12	13	14	15	16	17	18	19	20
Metres	3·35	3·67	3·96	4·27	4·57	4·87	5·18	5·48	5·79	6·09
Feet	21	22	23	24	25	26	27	28	29	30
Metres	6·40	6·70	7·01	7·31	7·62	7·29	8·23	8·53	8·84	9·14
Feet	31	32	33	34	35	36	37	38	39	40
Metres	9·45	9·75	10·06	10·36	10·67	10·97	11·28	11·58	11·89	12·19
Feet	41	42	43	44	45	46	47	48	49	50
Metres	12·50	12·80	13·10	13·41	13·71	14·02	14·32	14·63	14·93	15·24
Feet	55	60	65	70	75	80	85	90	95	100
Metres	16·76	18·29	19·81	21·33	22·86	24·38	25·90	27·43	28·95	30·48
Feet	105	110	115	120	125	130	135	140	145	150
Metres	32·00	33·52	35·05	36·57	38·10	39·62	41·14	42·67	44·19	45·71
Feet	155	160	165	170	175	180	185	190	195	200
Metres	47·24	48·76	50·29	51·81	53·33	54·86	56·35	57·90	59·43	60·95

The Dredger.

Delays and Losses which Affect Costs.—It is the object of this chapter to deal with delays which in practice may be inherent to dredging work and also to those which frequently become attached but are not inherent or necessary. The inherent delays to continuous dredging are, *e.g.*, stoppage of work to allow large vessels to pass, shifting moorings of dredger, suspension of work in order to change worn buckets and other parts. Buckets may become foul especially in dock dredging requiring clearance, the remedy lying in prevention of *debris* falling into the dock from the loading berths.

There are delays owing to fog. These delays are twofold: Delay to the dredger owing to inability to locate marks and note progress; and delay owing to hopper fleet becoming fog bound—thus causing an interruption of the service of hopperage.

Such delays and losses as we have enumerated are practically unavoidable. Let us consider some cases of delays which are not inherent. Breaking of moorings probably accounts for more delays than any other avoidable source, in the case of heavy bucket dredgers working in a channel. Every occasion of chain breaking should be noted in journal and the cause

investigated. For the larger diameters side-welded chains are preferable, being joined by the side link weld where the wear is least.

Dredging chain should be specially tested—by selected lengths from the finished cable and the ultimate breaking strain found. To adopt the strain given on a certificate where the load test is made by gradual tension on a table is to exclude conditions actually found in open channel dredging. Dredging chains require to suffer shock, torque, jerk, torsion, surging, and kinking strains. The leading lightship authorities, such as the Trinity House, Irish Lights Commissioners, Mersey Docks & Harbour Board, Calcutta Port Commission and Railway Dock Companies, use side-welded chain made to a special test specification for underwater work.

Inadequate dredging plans in a progressive programme may prove a source of delay, and therefore the hydrographic features shewn on scales which are large without being inconvenient should be considered in advance.

The instruments used for fixing position as the dredger progresses should be calibrated periodically, and errors noted on the instrument box. This applies particularly to the sextant and station pointer.

Co-operation between the surveyor (hydrographic) and dredging master is essential; the soundings reveal the accuracy or inaccuracy of the work done. Where a steam hopper fleet is used to convey dredgings to sea—the "distance steamed per ton of coal," "the average speed from dredger and *vice versa* to deposit site," the total mileage *per mensem*, form useful factors in the economics of running steam hoppers. Dates of hull cleaning and boiler cleaning should be noted in the margin of these returns.

In heavy weather hopper door chains are liable to be damaged when releasing the load, due to the rolling or plunging of the ship. Great care is then required to prevent the sudden strain which is the cause of this type of casualty.

Hoppers designed with straight sides to the hopper well

release loads more effectually than those of V formation. This point in original design is important if the hopper will be employed in carrying clay.

Hoppers employed in carrying fine sand should be dry docked or grounded in a suitable position and be fitted with felt-packed battens to prevent the sand running out when being loaded. Sand may be hard as to be impossible to remove by suction, and the bucket dredger with attendant hopper in these circumstances are the implements to use. The foregoing form some of the delays which affect costs.

Stores issues and stores losses form a part of the common costs in running a dredging fleet. It should be a rule that stores or equipment lost cannot be replaced by the operation of demanding or indenting for a renewal. Special forms or reports should be used for the replacement of losses, together with an explanation of the loss.

The ratio of maintenance costs of the plant to the total cost of running the dredging units should be carefully scrutinised.

Classification affects expense in this matter. Dredging units classed at Lloyd's, Bureau Veritas, etc., demand a high standard of maintenance. It is questionable if dredgers employed solely in docks raising mud require as high a standard as a seagoing vessel.

The dredging programme may and usually does produce changes in depth which affect costs—this condition requires to be kept in mind when anticipating expenditure. When a waterway first comes under development the material is plentiful and the depth not considerable; under these conditions costs should at this stage be lower than when the material is more scattered, less easy to excavate, and depth is greater than in the early stages of the programme. More time, more wear and tear, more effort are necessary as the depth is increased thus raising the cost.

Collaboration of the several persons—the surveyor, the dredger master and others concerned in the work—with a view to the prevention of misunderstandings is desirable.

The selection of the dredger master for the specific operation he will be employed on is frequently contributing to success or otherwise. Some dredge masters accomplished at bucket dredging do not take to grab dredging with similar aptitude.

Suction dredging is totally dissimilar to either grab or bucket work in its management of the vessel and therefore the aptitude of the man in charge requires supervision without previous experience.

The Dredging Programme.—The same applies to suction dredging. To obtain and/or select the right man for the right job discussion with subordinates is necessary. Suggestions of value quickly arise in the minds of men who see the points which need attention. Prospective programmes should therefore be issued and the features discussed with the participating officers, thus leaving no room for misunderstandings.

Such matters as the probable life of a top tumbler, the dates for boiler cleaning, etc., are examples of matters which personal contact serves to solve beforehand.

The length of head and stern cable to be used, the question of low or high gear (slow or fast dredging), alternative use of bucket sets, some dredgers having two sets, *i.e.*, for hard material and large for soft material.

Marking of side cables when working to a precise cut is a matter for careful consideration.

Arrangements for securing anchors when working at short range where there are no facilities for securing to a pier or dolphin. Burying buckets on foreshore has sometimes been found effective. Patent anchors staked down with short piles are also safe and effective.

Diving.

It appears desirable when dealing with submarine work such as dredging to say something about diving. In other pages we deal with the use of underwater pneumatic drills by divers and similar operations.

We give *in extenso* on other pages with other notes, orthodox

methods of dressing the diver and sending him down but diving is the subject of much which is unorthodox.

In salvage work, for instance, the signals are prearranged for the particular circumstances, between the diver and his attendant, consisting of pulls and shakes as requisite.

As a rule the air pipe is not used for signalling. Before descending if the work involves the use of hammer, wrench, bolts, chisels, oakum, etc., it is simple to agree on a code for the occasion.

Strength of Tide in which Divers can Do Useful Work.—The strength of tide or current in which divers can do useful work is often the subject of debate amongst those engaged in submarine operations. Divers themselves frequently miscalculate the velocity, their estimates tending, quite unwittingly, to exaggerate it.

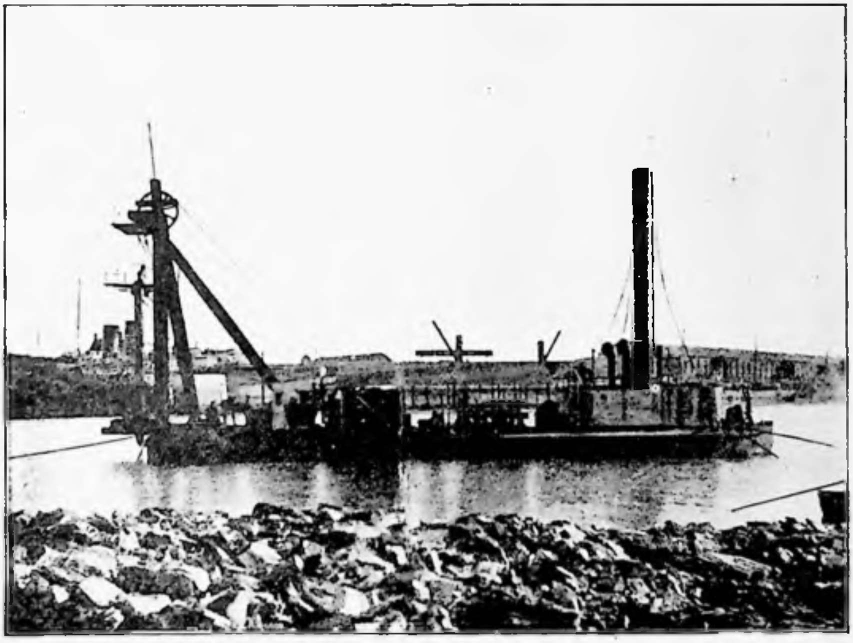
Speaking generally, however, the strongest current in which a diver can do useful work is from 2 to 2½ knots. When it is more than this the strain on air pipe and life line is liable to pull him away from his work, unless he is lashed to it. But if he is sheltered—say in the hold of a ship or behind a wall—the current does not affect him except on his way up and down.

In all cases where the velocity is, say, 1·5 knots and upwards, it is necessary for the diver to make himself heavier than usual by wearing a weighted belt, not unlike a cartridge belt, which can be loaded with weights as required; this in addition to the usual chest and back weights.

The extra weight necessarily somewhat increases the diver's labours on the bottom but that is unavoidable. As to the time taken to reach the bottom of the tideway, the following table gives the result of the diver's descent to a depth of 20 fathoms in tides down to 1½ knots velocity.

Tide	Reached bottom	Depth
0	About 50 seconds	20 fathoms
½ knot*	1 minute	20 ,,
1 knot	1¾ minutes	20 ,,
1½ knots	2½ minutes	20 ,,

* Knot being 6080 feet.



The Tilbury Contracting Coy.'s Rock Breaker at work in Holyhead Harbour.

Superficial Area and Displacement.—The superficial area of an ordinary sized man's body is about 2160 square inches, so that in atmospheric air the total pressure is approx. 2160×15 lbs. $= 32,400$ lbs. At a depth of 33 feet of sea water, the total pressure would be 64,800 lbs. (or double the atmospheric pressure). So long as the pressure is equally distributed throughout the body by the body fluids it has no effect.

Buoyancy of Submerged Objects.—A submerged body displaces in the sea a weight of water equal to the cubic capacity of that body or vessel $\times$ 64 lbs. (the weight of a cubic foot of sea water). Thus a pontoon or vessel, measuring 15 feet long $\times$ 4 feet $\times$ 3·1 feet displaces if entirely submerged 186 cubic feet or approx. 5·5 tons.

Cubic foot of salt water weighs 64 lbs.

Cubic foot of fresh water weighs 62·5 lbs.

Pressures.—Every 1 foot depth of salt water increases the pressure by nearly $\frac{1}{2}$ lb. on 1 square inch.

Dressing the Diver and Sending Him Down.

Duties of Those in Charge of Diving Operations.—A strong broad-beamed boat should always be used for diving operations. Having got everything necessary into the boat, arrange the position of the ladder and pump. The pump must be out of the way of the diver and the men attending him; it must be placed so that the attendants can have a clear view of the pressure gauges, and so that the men working it may have as much room as possible. Secure lashings are to be passed to ensure the pump being quite rigid in the boat. While the diver is dressing, the pump should be got ready. The pump should always be worked in its chest. The iron caps protecting the crank ends should be removed, the nuts securing them being replaced. The fly wheels should then be fitted on the crank shaft, the winch handles shipped, and the nuts on the end of the shaft well screwed up with a spanner.

The hinged flaps covering the pressure gauges and the flap at the back of the pump case should be opened, the screw

cap on the overflow nozzle of the cistern removed, and the cistern filled with water; the caps of the air delivery connections should be removed; the necessary length of air-pipe should be put together carefully with leather washers in place, the union nuts being tightly screwed up by means of spanners supplied. The air-pipe should be tested till the pressure shown on the pressure gauge is considerably above that corresponding to the depth to which the diver will have to descend. When the desired pressure has been attained, the pump should be stopped and the gauge watched to see if there be any leakage in pipe or connections. Unless a blank cap be used, a rough-and-ready method of holding the pressure is to press the palm of the hand over the open end of the pipe. If a two-cylinder double-acting pump be employed, *each cylinder* should be tested. If only one diver is going down, his pipe must be joined up to the left-hand delivery nozzle on the pump.

Testing Inlet Valve on Helmet.—Before screwing the air-pipe to the inlet valve connection of the helmet, a finger should be inserted into the valve in order to see that it is free on its seating and that the spring is working properly.

Joining up Air-pipe and Signal Line.—The air pipe and breast-rope (signal line) are now joined up to the helmet. Care must be taken that the plugs of the telephone cable are entered in the proper holes before screwing up the nut on the breast-rope, that the inlet valve on the helmet is correct, and that the leather washers of air-pipe couplings are in place before the pipe is screwed up. Two spanners are always to be used in joining up lengths of pipe and in connecting the pipe to the helmet.

The breast-rope should now be joined up to the battery box and the telephone tested.

Air-pipe and breast-rope are to be coiled down in large flakes out of the way so that they may run out easily.

Dressing the Diver.—The diver puts on the woollen guernsey, drawers, and long stockings supplied. If cold weather, he should put on two or more suits of flannels. If the red woollen cap is worn, it must be pulled down close over the head, care

being taken to leave no loose end which might possibly obstruct the air outlet.

The *shoulder pad* (if one be worn) is put on and tied under the diver's arms. He then gets into the diving dress, which in cold weather should be *slightly warmed*, an assistant lifting it well up to allow him to get his shoulders in easily; he next puts his arms into the sleeves, the assistant opening the cuffs by inserting the first and second fingers of both hands, taking care to keep his fingers straight. The diver, by pushing, forces his hand through the cuff (cuff expanders are also provided for this operation). A little soft soap rubbed on the inside of the cuff makes this operation easy. If required, he puts on a pair of outside stockings and a canvas overall, to preserve the dress from injury or undue chafing.

Corselet (*Breastplate*) *Straps*, 12-bolt type.—The diver then sits down, the inner collar (or bib) of the dress is drawn well up and tied round the neck; then the boots and the breastplate are put on, great care being taken that the india-rubber outer collar of the dress is not torn in putting it over the projecting studs of the breastplate. The four jointing straps (in the case of the 12-bolt helmet) of the breastplate band are then put over the studs and down on to the rubber collar, the thumbscrews are then run on to the studs; before tightening up the screws, the shoulder holes of the collar of the dress must be borne close up to the studs on the breastplate, and the thumbscrews next on each side of that joint screwed down first, the diver holding his arms well up to assist; *the thumbscrews at the joints are the last to be screwed down*; the overall dress is then adjusted, and the wrist rings are put over the cuffs. If gloves are used, rings are put over these, as well as the cuffs.

Corselet (*Breastplate*) *Straps*, 6-bolt type.—In using this type, when the metal straps are dropped over the corresponding projections on the rubber collar of the diving dress, the two *front* and the two *back* nuts should be screwed down first before screwing down the central nuts at the joints on the shoulders. It is a mistake to use great force in screwing up these nuts

with the T spanner supplied (whether the 6-bolt or the 12-bolt corselet be used), as by so doing the straps are frequently bent out of shape, and instead of making a tight joint it sometimes has the opposite effect.

Putting on the Boots.—The boots are put on with the buckles outwards; the lanyards should be well secured round the ankles, otherwise the boot might get pulled off, especially when working on a muddy bottom.

The Helmet (*without the front glass*) is then put on, and screwed hard into place, the stop (lock-pin) at the back being turned down. The breast-rope and air-pipe are brought up under the right and left arms respectively, and secured to the front of the corselet by lanyards, rolling hitches being employed.

Knife.—A knife should always be worn, carried at the left side. The waistbelt must be prevented from slipping down either by reeving it through the bight of the air-pipe or by making use of the buckle and strap provided.

Wrist Rings.—These are put on last thing, before the diver gets on the ladder.

The Pump is now Manned and hove round a turn or two, so that the diver can tell that the pipe is properly joined up by hearing the rush of air into the helmet.

He then gets on to the Ladder, the attendant keeping the breast-rope and air-pipe in hand, lest the diver slip overboard. The diver having been properly placed on the ladder, the attendants place the pipe and breast-rope outside it and take a complete turn with each round the sides while they put on the weights.

Putting on the Weights.—The weights are then put on, the back one first, the lanyards being brought over the hooks on the helmet, rove through the rings in the front weight, and secured with a bow hitch. The long lanyard is then brought round the waist, rove through the thimble in the front weight, and secured at the left side by a reef knot. If using the clips, the front weight is put on first, the clips being placed over the tabs on the breastplate; the back weight is then put on, the

clip lashings over the hooks on the helmet, the two being secured to the diver's body by the lanyard round the waist.

All Ready for Descent.—When the attendant is satisfied that all is correct, and that the diver understands the signals, he orders the pump to be hove round and screws up the front glass securely; this done, he takes hold of the life-line and pats the top of the helmet, which is the signal for the diver to descend. The ladder should always be used when going out of and coming into the boat, and the shot-rope to descend and ascend by.

Any leakage in the dress can be detected if the diver stops when his head is just under water and presses his finger on the outlet valve spindle for a few seconds.

Attendance.—Each diver while under water requires an attendant to hold the breast-rope and air-pipe. The official in charge of the operations should see that the pipe and rope pay out clear.

The post of attendant is a very responsible one. From the time the diver gets on the ladder to go down till he comes up again, the attendant must concentrate his mind on his charge and never let his attention wander. The breast-rope and air-pipe must be held clear of the gunwale and *moderately* taut, so that the movements of the diver can be felt and a rough idea formed of what he is doing. But care should be taken not to have them so taut as to inconvenience the diver.

The attendant should frequently glance at the pressure gauge of the pump to ascertain any changes in depth, and he must always know whereabouts the bubbles are coming up and the direction in which they are moving. Where there is much rise and fall of tide he must see that the shot-rope is frequently hauled in or lowered, so as to keep the shot on the bottom and the rope taut.

When the diver is working on a ship's bottom or other place from which he might fall, the attendant must be on the alert to catch him with the breast-rope (signal line) and pipe should this happen, and should the breast-rope be paid out for

any reason, such as sending down another rope or a slate, he must see that the air-pipe is kept well taut in case of a similar accident. It is better, however, to use a separate rope for sending down articles to the diver.

When two or more divers are down together, the attendants should do all they can to prevent them from getting foul of each other, watching the two sets of bubbles, and warning the men by pre-arranged signal or by telephone if need be.

Pressure Gauges.—Great attention must be paid to the pump gauges. Should they fall quickly, it shows that either the diver is coming up or that something is wrong with the apparatus; the signal should be at once made to the diver asking if he is all right. If he replies that he is coming up, the pipe and breast-rope must be gathered in smartly. Should, however, the diver signal back "All right," and the gauges still continue to fall, something must be wrong with the apparatus and the diver must be at once called up. If the gauges rise quickly, it shows that the diver has fallen; ask the diver if he is all right. If he signals "All right," he has recovered himself; if no reply is received, *he must at once be hauled to the surface but not too rapidly.*

If the diver has any difficulty in getting under water, or should he be blown up from the bottom, the attendant must use his discretion and ease or stop the pump, until the surplus air has been got rid of. If the diver cannot help himself, the outlet valve and tap on the helmet must be opened, or the cuff pulled open, so as to let the excess air escape. *Be careful to have the pipe and rope well in hand so that the diver cannot drop down suddenly.*

If the diver, on coming up, has a number of turns round the shot-rope, and it is difficult to take up the slack of the air-pipe and breast-rope, it is better to pull up shot-rope, air-pipe, and breast-rope all together.

Diver Coming Up.—When the diver comes up, the front glass should be at once removed. If he is soon going down again, he can have his wrist rings removed, and can take the

weight off his body by leaning forward and resting the front weight on the gunwale or ladder; if he is to cease work or to remain up a considerable time, the weight should be removed and the diver assisted into the boat and his air-pipe and breast-rope disconnected. He can then have his helmet removed. If he has ceased work the waist-belt and boots are next removed, then the overall dress (if worn). The breastplate bands should then be removed, the thumbscrews at the junction of the bands being unscrewed first; the bands being removed, the outer collar should be taken off with care to prevent the threads of the studs tearing the edges of the holes in the indiarubber in getting the collar over the screws; the breastplate and dress are then removed, the assistant's thumbs being used to enable the diver to withdraw his hands from the cuffs; the shoulder pad and other clothes are then taken off. After the day's work is over, the instructions as to care and management of gear must be carefully carried out before stowing it away.

SIGNALS BETWEEN DIVERS AND ATTENDANTS.

FROM DIVER TO ATTENDANT.

On Breast-rope:—

1 pull means - - "I am all right."
2 pulls mean - - "Send me a slate."
3 pulls mean - - "Send me a rope."
4 pulls mean - - "I am coming up."

On Air-pipe:—

1 pull means - - "Less air (ease pump)."
2 pulls mean - - "More air (heave faster)."
3 pulls mean - - "Take up slack pipe and breast-rope."
4 pulls mean - - "Haul me up."

WORKING SIGNALS OR BELLS.

On Breast-rope:—

1 bell means - - "Hold on."
2 bells mean - - "Pull up."
3 bells mean - - "Lower."
4 bells mean - - "You are holding me too tightly."

CLEANING SHIP'S BOTTOM (using a stage).

On Air-pipe:—

1 pull means - -	"Foremost starboard rope."	Followed by the ordinary "Pull up" or "Lower" signal.
2 pulls mean - -	"After starboard rope."	
3 pulls mean - -	"Foremost port rope."	
4 pulls mean - -	"After port rope."	

SIGNALS FROM ATTENDANTS TO DIVERS.

DIRECTION SIGNALS.

On Air-pipe:—

1 pull means - - "Search (or remain) where you are."
2 pulls mean - - "Go straight ahead."
3 pulls mean - - "Go to the right."
4 pulls mean - - "Go to the left."

The "right" and "left" signals should be obeyed as follows: —On receiving *three pulls*, the diver is to face his own shot-rope, or whatever corresponds to it, and then move to his *own right.* On getting *four pulls*, he is to face his shot-rope, and then go to his *left*.

On Breast-rope:—

1 pull means - - "Are you all right?"
2 pulls mean - - "Am sending a slate."
3 pulls mean - - "You have come up too far. Go down slowly till we stop you."
4 pulls mean - - "Come up."

A rapid succession of pulls on the breast-rope or air-pipe is the call used when the telephone bell is out of order, or in cases where the telephone is not employed.

Other signals will, of course, be arranged between diver and attendant to suit the exigencies of the particular work in hand. *But where the telephone is used this method of signalling can, of course, be dispensed with.*

"*Foul*" *Signals.*—Foul signals can be made on either air-pipe or breast-rope, whichever is clear. Two bells, repeated several times quickly, mean that the diver is foul and requires the assistance of another diver. Three bells repeated several times in quick succession mean that the diver is foul, but can clear himself if left alone.

Notes on Signals.—All signals made and received, and all sudden movements of the diver, or anything that seems to show that he is in difficulties, are to be reported immediately to the officer or superintendent in charge on the spot. The person receiving a signal repeats it to show that he has understood it; *never answer a signal in this way unless you clearly understand what is meant*; if you get a wrong answer to your signal, or none at all, go on making the signal until it is correctly answered.

The attendant should, from time to time, ask the diver if he is all right, and if no reply can be obtained the diver must be hauled up under the direction of the officer or superintendent in charge.

If the breast-rope and air-pipe get turned round the shot-rope, it may become impossible to get "pull" signals through, and the turns must be taken out from the boat as soon as they are noticed.

Do not try to make signals on a slack rope; pull up a foot or two till the diver can be *just* felt, and then make the signal gently but distinctly. A sudden or violent jerk may, by striking the helmet up against the diver's head, cause him injury.

Remember that a diver at work may sometimes be in such a position that he cannot answer your signals for several seconds, so allow him reasonable time before you repeat them.

Holding the Breast-rope and Pipe.—In attending the pipe and rope, give the diver 2 or 3 feet of slack when he is at the bottom, but just feel the weight of the man from time to time to make sure that you have not got too much slack out.

It is extremely embarrassing for a diver to find his pipe and rope too taut, so that his head is being continually pulled away from his work. As it is difficult for him (without the telephone) to make his attendants understand that they are holding him too tightly, special care must be taken to avoid this.

Interpreting Signals.—Judgment must be used in inter-

preting signals, and the attendant must consider what they are most likely to refer to. For instance, suppose a diver is going down, and you are his attendant and hold the breast-rope. You should know from the gauge when he gets close to the bottom, and if you get one pull about that time it means, of course, that he has reached the ground; but if you were to get one pull while the gauge showed that the diver had not yet reached the bottom the meaning would be "Hold on"; the diver has probably let go the shot-rope, or for some other reason is unable to stop himself and wants to be held by the pipe or breast-rope. If you get two *bells* immediately after the diver has signalled that he has reached the bottom, the meaning would be that he wanted you to pull up the shot-rope (which is probably too slack). When it was properly adjusted he would signal "Hold on," when you would turn it up.

Two *bells* immediately after the diver has signalled that he is coming up mean that he wants to be pulled up. Do this very gradually. If there was anything seriously wrong, the diver would have signalled to be hauled up by giving four pulls on his air-pipe.

On going down, the diver, before leaving the surface, will signal by waving his hand that he is ready to do so.

The attendant answers this signal by one pull on the breast-rope. The diver must not be allowed to go down the shot-rope until he has made the above signal.

Four pulls on the air-pipe are an emergency signal, and the diver must never use it unless something serious has happened. There must be no delay in obeying it.

Sending Down a Rope or Slate.—In shallow water, where there is little chance of the diver getting foul, the procedure in sending down a slate to the diver is as follows:—First make sure that the diver has no turns round his shot-rope. On receiving two pulls on the breast-rope from the diver the attendant attaches a slate, with a pencil, to the breast-rope; he then gives one pull on the breast-rope. The attendant will pay out the breast-rope, and the diver will steadily gather

down the slack until he gets the slate. The diver gives one pull on the breast-rope when he wants the attendant to take up the slack of the breast-rope again.

The same routine is adopted in sending down a rope. After attaching this rope to the breast-rope, the former is taken well forward or aft to prevent turns getting round the latter when the diver gets the rope. He must be careful not to dip it between his air-pipe and breast-rope.

In deep water or in a strong tideway the foregoing method is dangerous and must not be used. Instead, a heavy shackle is to be shipped so as to slide down the breast-rope, or, if the air-pipe and breast-rope are seized together, a shackle large enough to travel easily down the two of them must be used. If a slate is being sent down, it is stopped to the shackle, which is lowered to the diver by a light line. A small rope to be sent down can be bent direct to the shackle, but in the case of a large rope, or wire, a heaving-line can be sent down by the shackle and the diver uses the heaving-line to haul down the larger rope.

Signalling when Air-pipe and Breast-rope are seized together. —Pipe and rope are sometimes made into one line by seizings, so as to lessen the risk of fouling when diving on a sunken wreck. It is then only possible to make a limited number of signals, and a special code must be devised according to the circumstances of the case and the nature of the work in hand, leaving out the signals which are least likely to be wanted. The following system of signals is inserted as a guide:—

FROM DIVER.

On Breast-rope and Air-pipe together:—

1 pull means - -	"I am all right."
2 pulls mean - -	"Send me a slate."
3 pulls mean - -	"Send me a rope."
4 pulls mean - -	"I am coming up."

FROM ATTENDANT.

1 pull means - -	"Are you all right?"

(When diver is ascending, 1 pull means "Stop.")

2 pulls mean - -	"Look out for the rope or slate which we are now lowering."
3 pulls mean - -	"You have come up too far. Go down slowly till we stop you."
4 pulls mean - -	"Come up."

The signals for "Pull up," "Lower," and "Hang on" would be the same as usual, except that they would have to be made on the air-pipe and rope together.

Rock Removal without Explosives.—For some years the method of rock removal by the Lobnitz system has been successfully followed. The cost of the plant is necessarily high so that the use of it is now arranged through contract rather than to build plant for such an operation.

Description of Cutter.—Briefly, the plant consists of a forged steel circular bar called the cutter, which is fitted with a removable point similar in form to a large projectile and made of armour piercing steel. In certain cases, a chisel point has been found more suitable for driving into very tough rock. A series of tooth edges have also been used as in rivers with a strong current where it was found difficult to ensure that the blows would be struck on the same spot every time. In every instance the fitting is adapted so that they can be replaced without necessitating the removal of the whole bar.

The bars are tapered according to the stresses due to the drop, their weight per metre of length being 1 ton. The composition of the steel for the points varies according to the material to be pulverised. For instance, what would answer for granite would not give such satisfactory results for limestone. The plant is built in sizes having rock cutters weighing from 6 tons upwards.

Working Conditions.—The principle of working such a rock cutter is that it is hoisted by a powerful steam winch and then released, and the cutter allowed to fall freely by its own weight on to the rock, the whole force of the blow being concentrated on a very small surface as many times as may be necessary

Tilbury Coy.'s Rock-Breaker showing Protective Guide Sleeve which ensures direct hitting.

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to effect the required disintegration. Special devices are employed to ensure that successive blows are struck on the right spot, and for quick hoisting and release. The barges from which the cutters are worked can be built self-propelling if required. The cutters are worked from the middle or at one end of the barge to suit the exigiencies of the work.

Results.—The average results from many works in hard rock is 2 cubic feet broken per blow, *i.e.*, broken to the most suitable size for dredging with a bucket dredger; which is more efficient than the grab dredger, because the jaws do not close readily owing to the frictional resistance of the stones. 150 blows per hour are delivered on the average, that is, equal to, say, to 10 cubic yards per working hour for a single cutter machine. The output of a double cutter plant is about one half more than that of a single cutter machine.

The later type of Lobnitz rock cutter has a sleeve guide which can be raised and lowered as requisite, in such a way that its bottom end is suspended about 2 feet above the top of the rock to be broken. In this way work can be carried out with the same length of ram when working in any depth from 10 feet to 50 feet—an important factor when there is a big range of tide—whereas with the earlier type of vessel where the ram itself worked in guides attached to the ship, a number of rams of different length were required to work at different depths.

One such implement was used by the Tilbury Company in the deepening of Holyhead harbour, where over 200,000 tons of rock were broken and dredged, the character of the rock being highly laminated micaceous schist.

Drilling Submerged Rock for Blasting by Explosives.—Much depends on the varying conditions under which work of this description is conducted that it is impossible to lay down any hard and fast rule for the carrying out of submarine blasting operations.

Of the two systems of power operated drills—pneumatic and steam—the former is undoubtedly the more economical and satisfactory.

Pneumatic or Compressed Air Drills.—Three systems are employed.

(1) Drills operated from a floating vessel or raft or from a staging.

(2) Hand drills, which the divers take under water with them.

(3) Tripod drills, which are heavily weighted and lowered under water, and are controlled by divers.

The most suitable pressure for pneumatic tools is 90 to 100 lbs. per square inch.

Approximate amount of work that can be done with pneumatic rock drills working in *granite* are as follows and represent work in the dry at the surface. In the altered conditions of submarine work the quantities would be somewhat less.

Hand Drills.—

Diameter of hole	Depth	Period
2 inches	45 feet	Per day of 10 hours
$2\frac{1}{4}$	50 ,,	,,
$2\frac{1}{2}$	55 ,,	,,
$2\frac{3}{4}$	60 ,,	,,
$3\frac{1}{8}$ and upwards	70 ,,	,,

Drilling Submerged Rock.

Tripod Drills.—With a $3\frac{1}{4}$ in. tripod drill, a whole $1\frac{1}{2}$ in. to $1\frac{3}{4}$ in. diameter by 4 feet deep can be bored in hard rock in 20 to 25 mins. Much depends upon the nature of the rock and whether it is solid or fissury. In the case of jointy rock, or rocks of uneven hardness, the time might be slightly increased. In determining the depth of holes, spacing apart and the size of explosive charge, the engineer will be guided by the peculiar conditions of the case in hand and the appliances available.

It should always be borne in mind that the disintegrated rock should be removed, therefore it should be blasted in pieces of such size as to be easily handled by the ordinary dredging appliances.

Regard must also be had to the proximity of buildings on shore, dock walls, river banks, etc.

Steam Power Drills.—In the removal of Elderslie Rock, River Clyde, at a short distance above Renfrew, this rock, a huge vein of "trap" 925 feet in length by about 325 in breadth, was removed by diamond drills worked by steam engines; for the greater part of the operations, which using this method commenced in 1880, was to give a uniform depth of 20 feet at low water spring tides.

The boring was done in longitudinal belts, in sections of five rows of holes transversely, by 40 feet long; the holes were 5 feet apart centres, and so that the holes would be opposite one another in each alternate row. Eight holes were bored, longitudinally simultaneously, then charged and blasted, and the other four rows dealt with in the same way.

When all five rows in the section had been bored, charged and blasted, the boring barge was shifted up stream and commenced operations on the next 40 feet long section, and an ordinary but powerful single ladder bucket dredger of small capacity following lifted the broken rock and left an open space for the next holes.

It was early found that where the depth of the hole was more than 10 feet the rock was not sufficiently disintegrated to enable the dredger to clear it freely away to the bottom of the holes, and the deeper portions of the rock were therefore taken in two depths or breaks, the first depth being bored to 17 feet at low water, blasted and dredged. The longitudinal belts of holes were continued from the south side outwards, into the middle of the river, until the whole ground in the southern half was cleared away to 20 feet at low water. The operations were then continued northwards until the whole depth of the river bed was cleared to 20 feet at low water.

Explosives Used.—The explosives used were Nobel's dynamite and blasting gelatine, tonite, and potentite. Dynamite was found most satisfactory, blasting gelatine proved the most powerful explosive for this work, but when frozen was more

dangerous to handle and more difficult to explode thoroughly. Tonite and potentite were found to be somewhat less powerful than dynamite.

Approximately 16,000 holes were bored, equal to about 90,000 linear feet. About 110,000 tons of whinstone or "trap" with boulder clay were dredged. About 76,000 lbs. of dynamite and other explosives were used without mishap, and were exploded by 35 miles of electric wire or cable and shot hole wire. The cost from first to last was £70,000.

Engines Used.—Two horizontal engines on the deck of the towing barge, supplied with steam from two boilers, drove the eight drills by a main shaft which extended the whole length of the barge.

The diamond boring tool was a steel annular ring $2\frac{1}{4}$ ins. in diameter and $\frac{1}{2}$ inch thick, studded with diamonds overlapping one another. This annular ring or crown was screwed on to the bottom of the boring rod, which in suitable lengths was carried inside an iron guide tube, extending down to the bottom of the river bed. The rod was connected at the top to a drill bar suspended from an iron framework on the barge. Rotary motion was given to the drills by phosphor-bronze bevel wheels, working in a frame and driven from the main shaft on deck by an arrangement of shafts and pulleys; which allowed for any lateral or vertical movements of the drill in rough weather, the rise and fall of tide, and the varying of the barge through wash or suction caused by passing steamers. The drill bar was driven at the rate of 400 revs. per minute, and during the whole time the boring was proceeding water, at a pressure of 40 lbs. per sq. inch, was forced down through the hollow boring rod to wash out the detritus and keep the face of the diamond crown cool. The pressure of the drill was applied by means of counter balance weights, varied according to the hardness of the rock being bored. In the hard blue whinstone the boring of the holes of $2\frac{1}{4}$ inch diameter proceeded at the rate of 2 feet per hour, and 5 feet per hour in the softer stone. When the necessary depth of hole was bored

the drill rods were withdrawn, and the dynamite charges were fitted with detonators and fixed in the holes. Attached to each charge were electric cables, which were led up to the surface of the water. All the charges were then connected, and the shot hole wires were attached to a main cable, which was carried to the positive and negative poles of an electric exploder. The barge was then withdrawn about 60 feet from the place of the explosion, and the row of eight holes was fired simultaneously, resulting in the displacement of approx. 100 tons of rock, the only disturbance on surface being a slight upheaval of water. The greatest amount lifted in one day was 280 tons. A diving bell went over the ground afterwards and removed any large stones which had been left by the dredger.

Use of Explosives in Dredging.—High explosive in dredging as in mining has assisted to expedite excavation. Blasting powder is now rarely used in modern practice. Gelignite and tonite are commonly used in underwater work with considerable success. The relative (approximate) strength, taking gelignite at 100 points, for other explosives are:—

Gelignite (full strength)	=100
Tonite and guncotton	= 85
Gelignite (50 per cent. preparation)	= 75
Loose blasting powder	= 30

The advantages claimed for gelignite are: (1) It is offered at cost equal to dynamite, but being more powerful is therefore relatively cheaper. (2) Its explosive energy is greater than dynamite by 12 per cent. (3) It is practically uninjured by damp or submersion in water for a reasonable period. Tonite is used extensively for dispersing submerged wrecks. When large charges are used the explosive is usually prepared in metal cases, packed with 1, 2, 3, 4, or 10 cubes of 5 lbs. each.

Sweeping to Ensure Proper Depths after Rock Dredging.—Although it becomes a tedious operation there is only one safe method to ensure that the dredging depths in rock dredging have been obtained. This applies to places where the tide

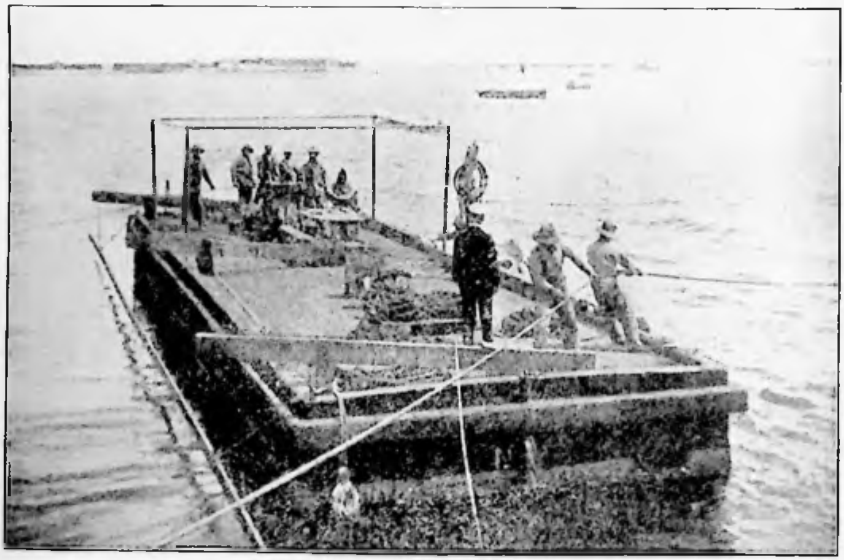
does not uncover the rocks to enable visual observation and levels to be made.

This method of verification is the suspended horizontal sweep—which may consist of a rigid bottom line or a horizontal ron bar or steel pipe suspended at the exact depth and towed systematically over each section dredged.

Careful marks must be set up on shore to guide those operating the sweep or else the area must be buoyed in such a manner that no part can be missed. The use of marks (whitewash will do) with back or transit marks are best.

The transit marks should be approx. three times the distance apart than the observer will be from the front mark. If the transit marks are too close accuracy is not served.

We show an illustration of a pontoon at work with horizontal steel pipe or bar temporarily raised while hauling into position to undertake another sweep.



We also show a sketch of another type of sweep (see p. 206). A spar between 60 and 70 feet is used. From each end a weight of 200 lbs. is suspended by a $1\frac{1}{2}$ inch manila rope, the weights

connected horizontally by a $\frac{3}{8}$ inch wire 50 feet in length, called the "bottom line," the depth or submerged distance from the spar being regulated by a measured line vertically over each weight and attached to the spar.

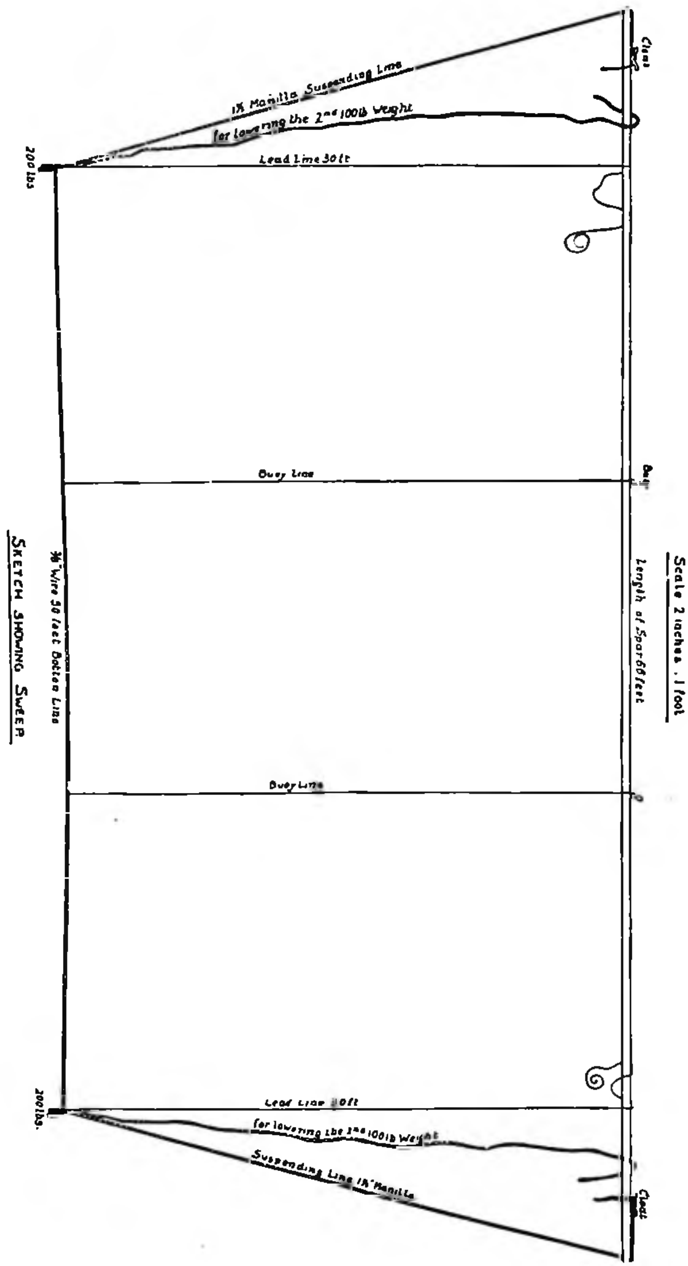
At distances of 16 at bow or/and 17 feet along the bottom line two light lines are attached, made fast above to small floats or pilot buoys, by length of line corresponding to depth of bottom line; these floats helped to indicate, by their change of position on surface or sudden submersion, relatively to their position with the spar, when the bottom line touched or is caught by an obstruction. According to the depth required to sweep below the sea surface, occasioned by the rise and fall of tide, or for other reasons, so are the weights lowered and raised and the attending lines adjusted.

Two motor boats or steam launches may be employed to tow the spar broadside to the tidal stream, provided the current is not too strong. The tow line can be attached to the positions where the leadline are secured, thereby making, say, 50 feet between the boats.

By securing to this point of the spar when adjustments have to be made the launch hauls back to the point required.

One boat may act as the directing one, working on transits, allowing each successive sweep to slightly overlap the previous one, sextant fixes being obtained to pilot progress of work as on a line of soundings. Weights of 200 lbs. are rather heavy for handling, but two sets of 100 lbs. can be used with facility. It has been calculated that the tension on the bottom line, between the weights, at a depth of 30 feet and using 200 lbs. at each end, was 52 lbs. If the buoyancy of the spar is sufficient greater weights could be used to increase the tension between them on the bottom line, thus assuming the character of a taut bar. The advantage of this method—which is slow owing to the light towage power used—is that there is less chance of hauling the sweep unawares over an obstruction by the pull being too strong in the towage.

Wire Ropes.—In the economics of dredging the care and


Sketch Showing Sweep
Scale 2 inches . 1 foot
Cleat
1½ Manilla Suspending Line
for lowering the 2nd 100lb Weight
200 lbs
Lead Line 30 ft
Buoy Line
Buoy
Wire 50 feet Bottom Line
Length of Spar 66 feet
Buoy Line
Lead Line 30 ft
200 lbs.
for lowering the 1st 100lb Weight
Suspending Line 1½" Manilla
Cleat

maintenance of wire rope become substantial factors. The cost of wire rope has advanced which renders economy more important.

Wires are used by dredgers for hoisting and lowering purchase in ladder bucket dredgers, for side moorings in all classes of dredgers especially in narrow rivers, docks, and canals.

We have also utilised wire for use as a spring attached to the head and stern chains of river dredging, and have found that the purchase wires when worn are still quite serviceable for this purpose. Wire is also used extensively for raising and lowering shutes of dredgers.

There remains, therefore, no need to explain the introduction of the diagrams of splicing and socketing and other matter which accompany the pictures.

We are indebted to Messrs. Bruntons for permission to reproduce the data and illustrations.

It should be noted in regard to specification for wire that No. 365, 1929 Report of British Engineering Standards Association on the British Standard Specifications for Shipping Wire, is available. This booklet deals with the recent standardisation, etc., *in extenso.*

Flexibility.—Wire ropes are made in varying degrees of flexibility to suit the particular working conditions for which they are required. The successful working of a wire rope depends upon its being suitably constructed for the work it has to do, and in consequence the question of flexibility is just as important as that of breaking strength.

In order that the maximum durability be obtained from a wire rope, it is essential that those wires taking the wear should be of as large a gauge as possible consistent with:—

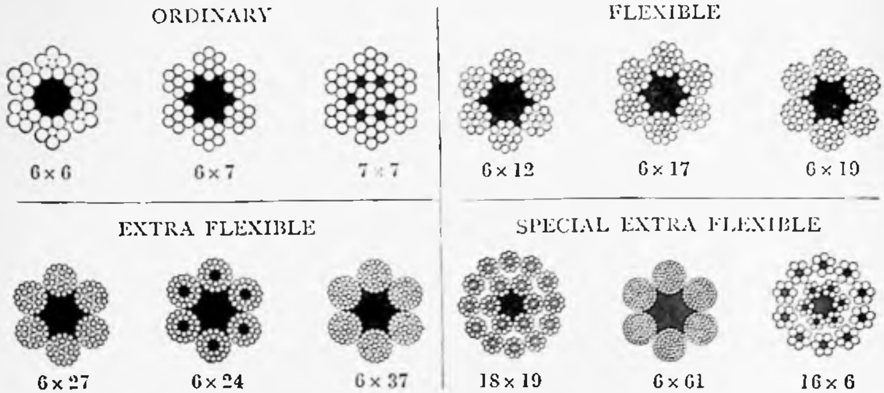
The dimensions of the drums and pulleys over which it works.

The speed at which the rope travels.

The nature of the work to be done, *e.g.*, haulage, winding, etc.

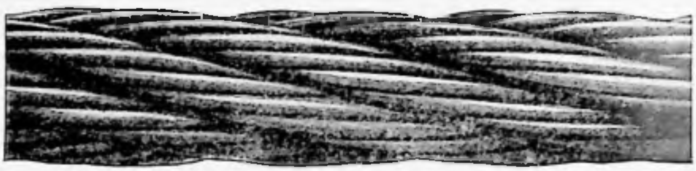
For practical purposes wire ropes may be divided into

four grades of flexibility, as illustrated by the undernoted standard constructions.

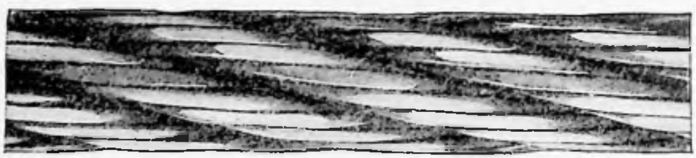


The Lay.—A wire rope is either made ordinary lay or Lang's lay.

Ordinary Lay.—In ordinary or cross lay the wires are twisted in the opposite direction to that of the strands forming the ropes. A wire rope made in this way is practically free from spin. It is suitable for crane and similar work.



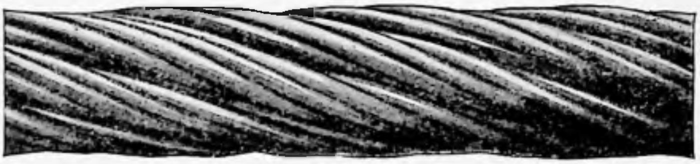
Ordinary Lay—New.



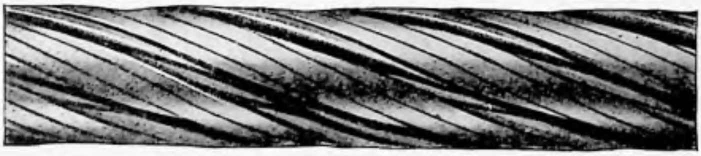
Ordinary Lay—Worn.

Lang's Lay.—This is sometimes known as Albert lay, and is that most generally adopted for mining under ordinary conditions. Its advantage lies in its greater wearing or contact surface. This will be at once apparent from the accompanying

illustrations. It will be noted that the wires forming the strands are twisted in the *same direction* as the strands forming the rope.



Lang's Lay—New.



Lang's Lay—Worn.

A Lang's lay rope is not suitable for a vertical lift without guides, as in the case of a crane where the load is suspended from the free end of a rope.

Tools.—Quite a few are required to cope with wire ropes of all sizes and classes. However, those mentioned will be found useful at all times.

Fig. 1.—Rigging screw or clamp, for securing both parts of the rope into the nose of thimble, with the aid of pin (Fig. 1A), which keeps the clamp clear of where the splicing starts.

Fig. 2.—D. clamp, for securing the thimble to the rope. These clamps are easily fixed and are more reliable than seizings. In fact, with three of these clamps and the aid of a vice, a thimble can be turned in perfectly tight and neat.

The following tools are required to successfully long-splice wire ropes: No. 1, Long marline-spike, and No. 2, short marline-spike for eye splicing. No. 3, Flat needle, for running the ends of the strands in. No. 4, Spoon, for pressing the strand into centre of rope. No. 5, Pair of splicing tongs, for preventing wire from turning whilst splicing.

Notes to Remember.—"That's good enough" *will not do.*

Nothing but the best should be put into splicing at all times. Another splice, a new sling, or a new rope, is cheaper than an

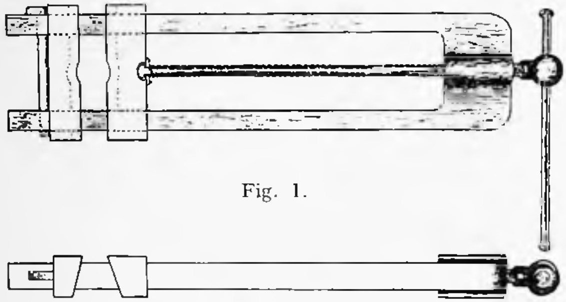


Fig. 1.

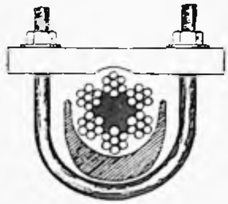
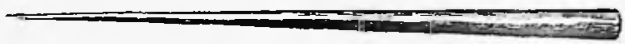


Fig 2..

Fig. 1A.

accident. When preparing a wire rope for splicing, it is advisable for the beginner to serve that part of the rope that forms

Nº1



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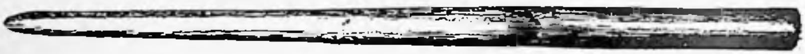
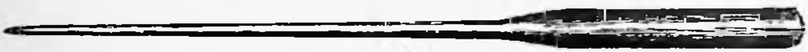


No 3



Nº3

Nº4

Nº5

the eye, otherwise the strands may slip back and bulge at the crown of the thimble, also to whip all strands whether

untwisted or not. The more the wires and strands are disturbed from their original formation the weaker the rope

Fig. 3.

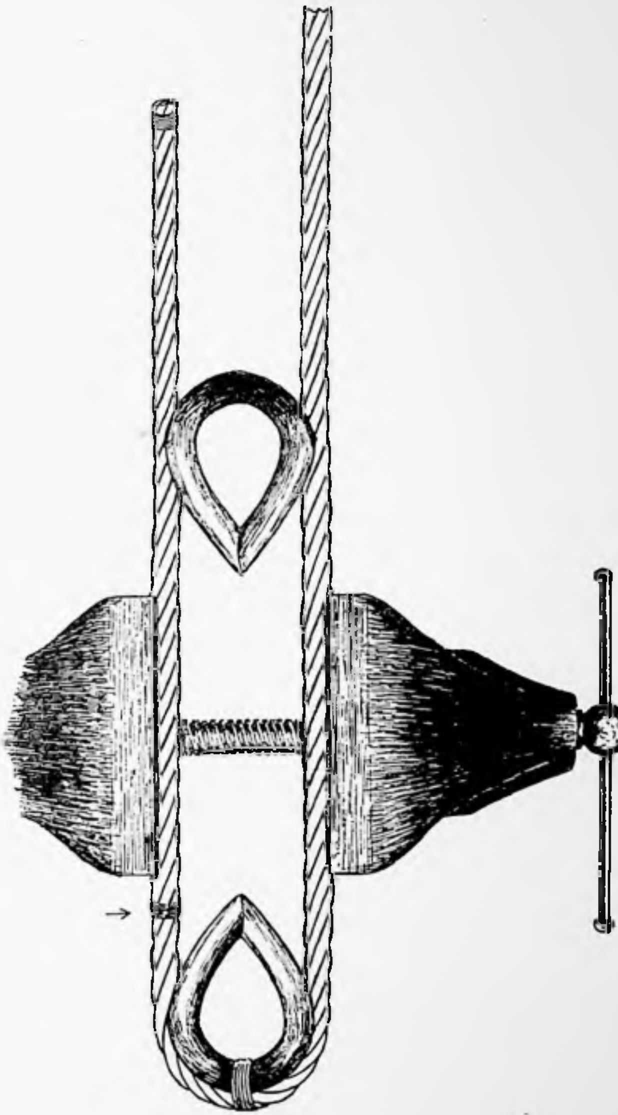


Fig. 4.

becomes. When splicing an eye in a wire rope with a fibre core, always remove the main fibre core. When splicing an

eye in a Lang's lay rope in other than the Liverpool style, the strands should be untwisted.

Turning-in a Thimble.—Method of turning-in a thimble with a vice, the jaws of which should be grooved, as shown in Fig. 3. This can be done in an ordinary vice, but is rather difficult and the sharp edges of the jaws are liable to damage the rope.

First mark off the length of rope required for splicing, and the circumference of thimble, also mark the centre of rope to form the eye, here seize or clamp the crown of thimble to the rope. Next open out the vice far enough to receive both parts of rope, care being taken to get the nose of thimble in line with jaws of the vice, as shown in Fig. 4. If the rope has not been served it is good practice to put a short serving of soft wire on the part to be unlayed, just below the nose of the thimble, as indicated by arrow in Fig. 4. This prevents the strands untwisting too far back. Next place a second but temporary thimble between both parts of the rope on the opposite side, keeping the nose in line with jaws of the vice as shown in Fig. 4. Now pull both parts of rope across the crown of thimble and secure them close up. Screw the vice hard home and fasten the permanent thimble in position by means of clamps or wire seizings, close up to nose of thimble, as shown in Fig. 5. This being completed, release the temporary thimble, open out the vice; the rope is now ready for splicing, and should appear as shown in Fig. 6, the thimble of which is secured by means of three soft wire seizings.

Tension.—It is as well to mention that when turning-in a thimble and splicing an eye, better results are obtained by splicing under tension, as the strands of the rope will close hard and tight on the strands being tucked as the spike is withdrawn, the tension being applied *after* the *first tuck* is made. Fig. 7 and Fig. 8 illustrate two simple methods of applying tension on a wire rope when splicing.

Eye Splicing.—The Lock or Over-and-under Style.—Having secured the rope as in Fig. 7 or 8, keeping the splicing ends to

the left, open out the strands three to the right and three to the left, here the short core may be cut out close down. The strand nearest the main wire to the right being No. 1, working to the left in rotation are Nos. 2, 3, 4, 5 and 6. Now insert the spike from right to left always, under two strands, and tuck No. 1 under the spike and in the opposite direction, as shown in Fig. 9.

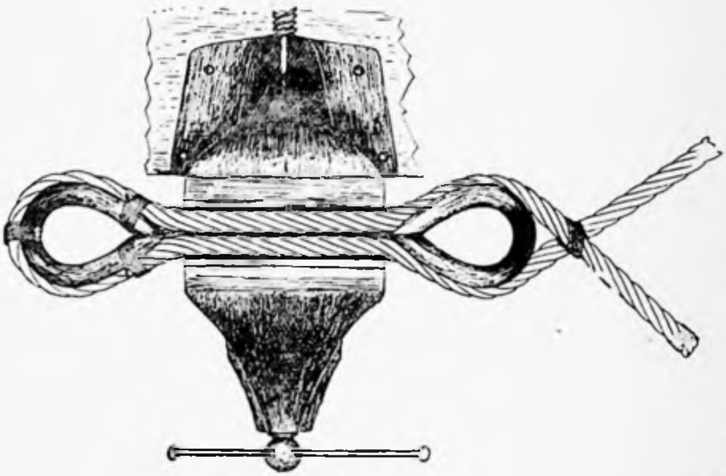


Fig. 5.

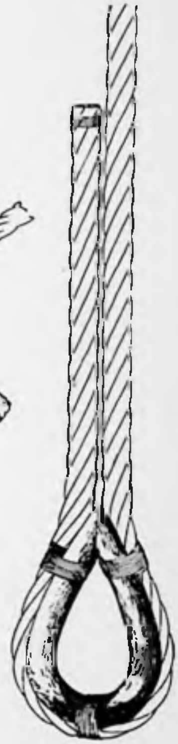


Fig. 6.

Pull strand well home before withdrawing the spike, insert the spike as before, only under first of the two strands that No. 1 went under, and tuck No. 2 as with No. 1, insert spike under the next strand to the left and tuck No. 6 as before, pulling strand well home, as shown in Fig. 10, but do not draw the spike. Next tuck No. 3 under and in the same direction as the spike went in. Insert spike under next strand to the

left as before, and tuck No. 4 as with No. 3. Lift the next strand to the left and tuck No. 5 as before, pulling the strands well home. This completes the first tuck, as shown in Fig. 11.

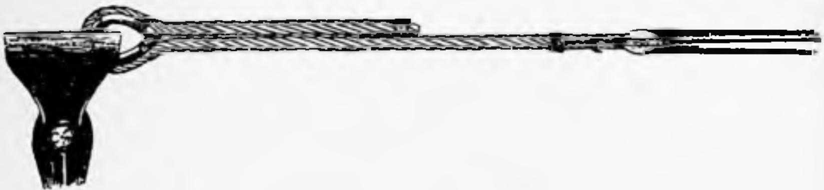


Fig. 8.

Fig. 7.

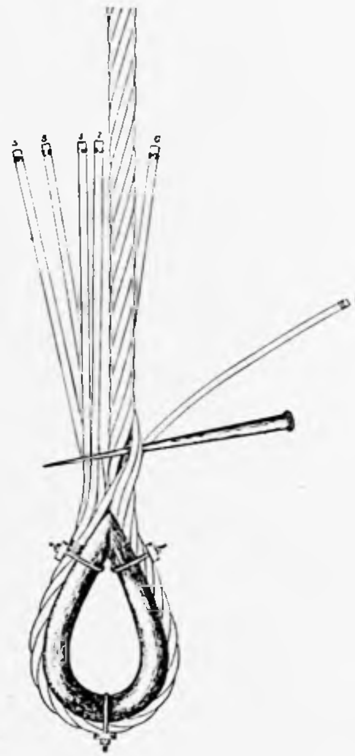


Fig. 9.

The next tuck should be started with the lower strand, that is the one near the eye or thimble, say the original No. 6, now No. 1. Insert spike under the second strand to its left, and tuck No. 1 under and in the *same* direction as the spike.

Thus the strands in this tuck go over one and under the next strand, as shown in Fig. 12.

Repeat the above operation with the other five strands in rotation, working to the left, pull all strands well home and beat with copper hammer or mallet. This completes the second tuck. Third and fourth tucks are exactly the same as the second, as shown in Fig. 13.

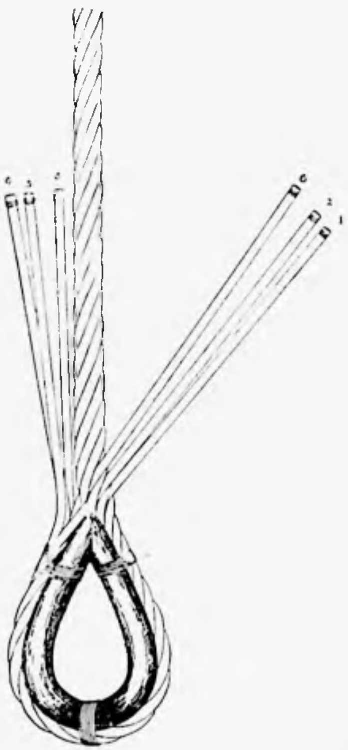


Fig. 10.

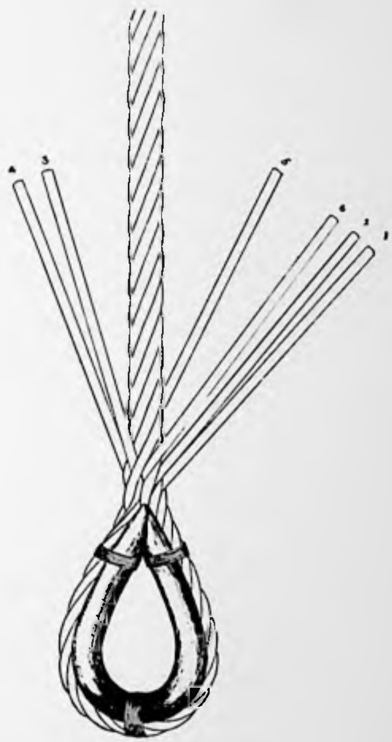


Fig. 11.

In the next tuck the strands are reduced by turning back one-third of the threads or wires, each strand is then in rotation tucked over one strand and under the next, as shown in Fig. 14.

This will complete the fifth tuck.

In this, the last tuck, *three* strands only are tucked, Nos. 1, 3 and 5 respectively, these in turn are tucked over one strand

and under *two* strands, by this means an effective lock for all strands and a neat taper is obtained. Now beat well round, cut or break off all ends, the splice is then complete as shown in Fig. 15.

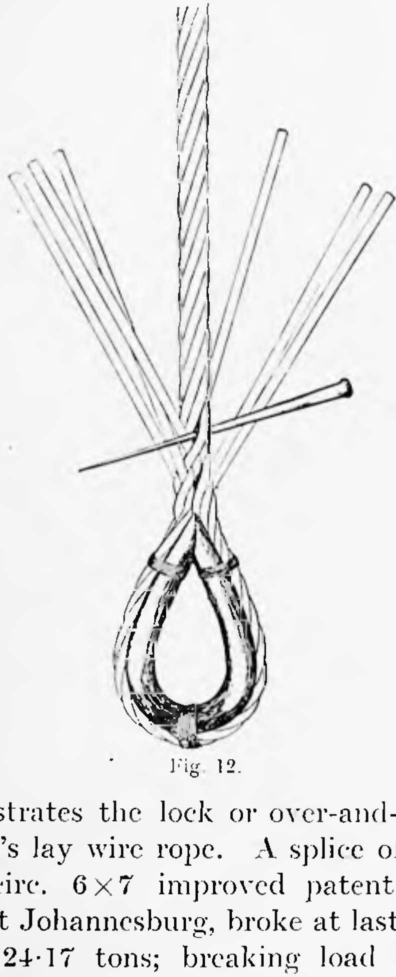


Fig. 12.

Fig. 16 illustrates the lock or over-and-under splice as it appears in Lang's lay wire rope. A splice of this description, made of $2\frac{1}{2}''$ circ. 6×7 improved patent steel wire rope, recently tested at Johannesburg, broke at last tuck of splice at: Breaking load, 24·17 tons; breaking load of rope 25 tons, spliced by T. F. P.

The French or "Liverpool" Methods (sometimes termed "Right-hand" Preparation).—As before, re-splitting strands and keeping the loose ends to the left, but do not cut the main core out, as in this style of splice the strands will lift away

from the main core which is not then large enough to fill the spliced part of rope. This causes a strand, sometimes two, to sink, but by twisting the short core around the main core as the strands are tucked, it increases in size and forms a bed for all the strands to close upon evenly. Work the spike as before, from right to left, and the strands in the opposite direction, always. Insert the spike through the centre of the rope, care being taken not to pierce the main core, and tuck No. 1 under the spike, pulling strands well home.

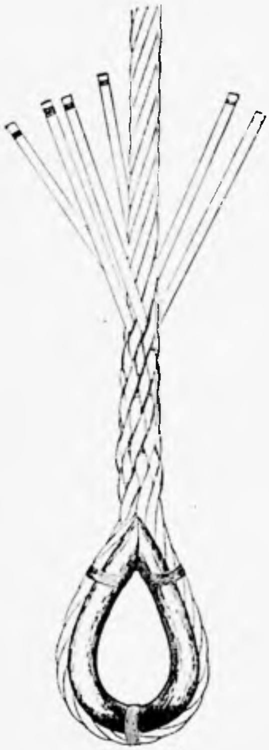


Fig. 13.

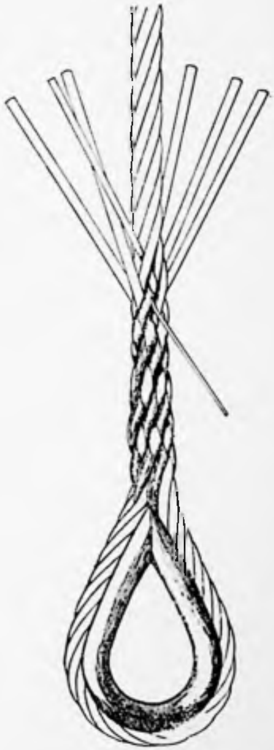


Fig. 14.

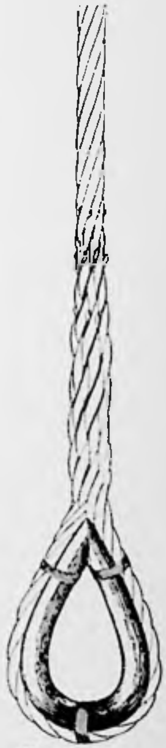


Fig. 15.

Next insert spike under the first two strands that No. 1 went under, and tuck No. 2 as with No. 1, insert spike under the first strand that No. 2 went under, and tuck No. 3 as with No. 2. Now tuck the core through the centre of wire as No. 1,

next tucking Nos. 4, 5 and 6 under one strand respectively, working to the left, as shown in Fig. 17.

Fig. 16.

Start the next tuck with the lowest strand—the original No. 1—insert the spike under the strand to the left of No. 1,

and by a slight twist up the wire with the lay, the core will be run in out of the way. Now tuck No. 1 under the spike in the opposite direction, and pull strand well home; repeat the operation with other five strands in rotation. The strands have now been twisted round their own particular strand in the rope, and this completes the second tuck, as shown in Fig. 18. The third and fourth tucks are made exactly the same as the second tuck, pulling all strands well home and beating round as each tuck is completed.

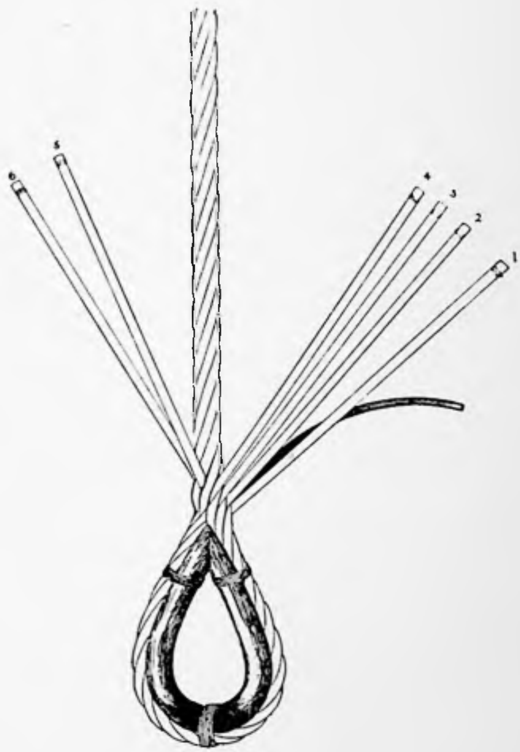


Fig. 17.

Before starting the next tuck, take out the lower third of each strand and bend them back, now tuck the remainder of the strands as before. This completes the fifth tuck. Sixth and locking tuck. Halve the strands, bending lower part

back and tuck all strands as before, only under two strands beat well, cut or break off all ends as shown in Fig. 19.

The reason for double-locking all strands in this style is to prevent the splice being drawn. Should the load be lifted on a single part of rope which is apt to spin, there is a danger of the rope becoming unlayed and the ends being pulled out when spliced, as shown in Fig. 20, termed the French or "Liverpool"

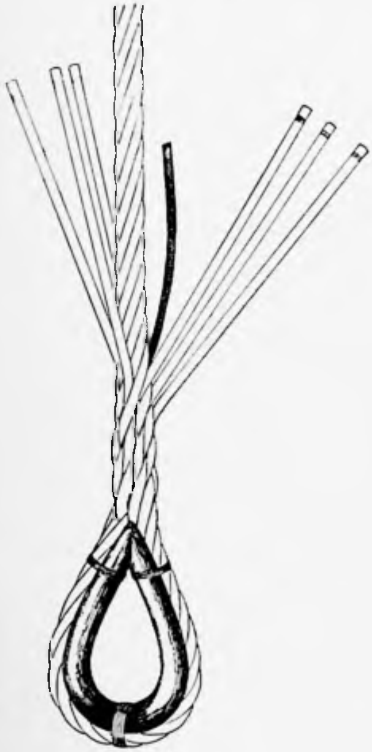


Fig. 18.


Fig. 19.

style. A splice of this description made of $2\frac{1}{2}$ ins. circ. 6×7 improved patent steel wire rope, recently tested at Johannesburg, broke at last tuck of splice at: Breaking load, 20·44 tons; breaking load of rope, 25 tons; spliced by G. S.

Fig. 21 illustrates the French or "Liverpool" splice as it appears in a Lang's lay rope. A splice of this description made of $2\frac{1}{2}$ ins. circ. 6×7 improved patent steel wire rope,

recently tested at Johannesburg, broke at last tuck of splice at: Breaking load, 23·37 tons; breaking load of rope 25 tons; spliced by T. F. P.

Fig. 22 illustrates a lock splice made in extra flexible plough steel wire rope 7×37.

Fig. 23 illustrates a French or "Liverpool" splice made in extra flexible plough steel wire rope 7×37. Both these splices are made in rope of ordinary lay.

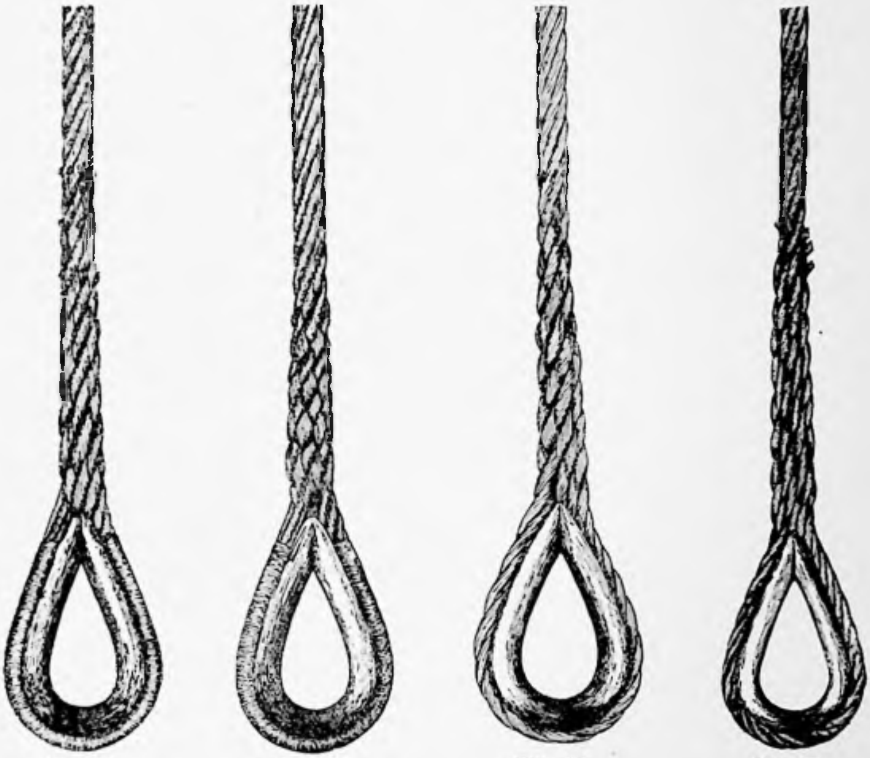


Fig. 20. Fig. 21. Fig. 22. Fig. 23.

Multiple Strand Ropes.—Wire ropes of more than six strands are frequently used, one of the best known being the "Kilindo," these vary up to 37 strands or more. Before going into the splicing, it is necessary to explain the construction of rope, as it determines how the strands have to be split; for

example, a "Kilindo" rope comprised of 18 strands, constructed 12 strands around 6 strands around a hemp core, the outer

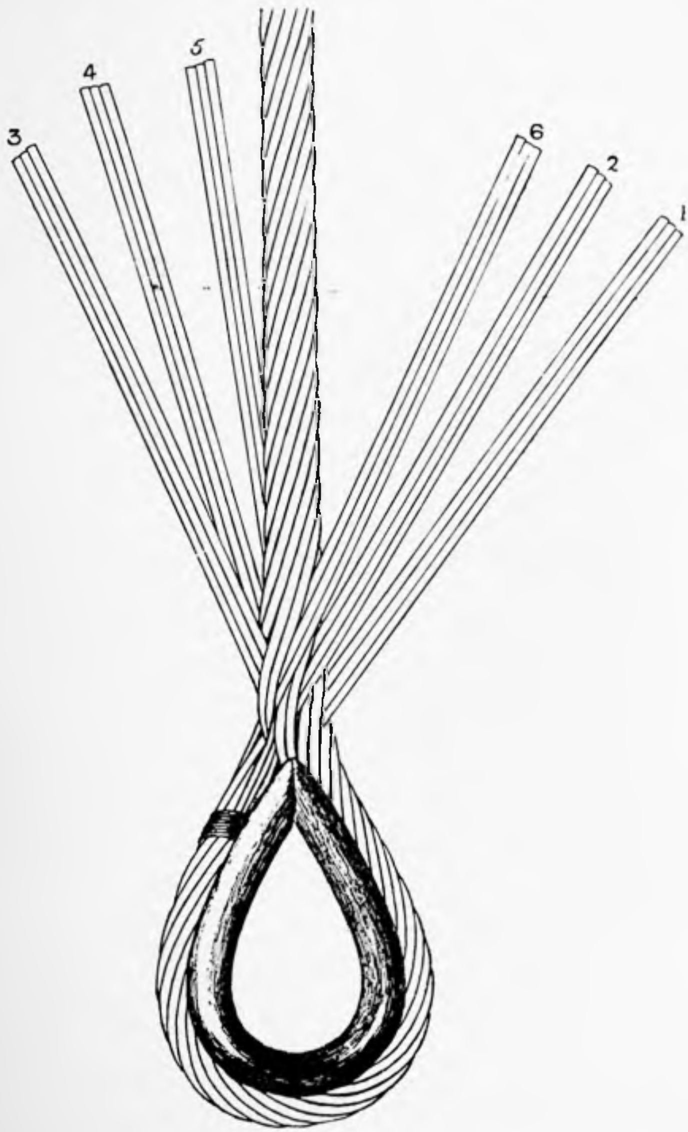


Fig. 24.

strands 12 split into 6 strands of two each, the splicing end, unlay the whole, which number 18, split up into 6 strands

of three each. Thus you have strands of three's tucking into strands of two's. Lay the strands out as before, care being taken that the strands do not cross each other, the main core of hemp may now be cut, having the main wire to the right and the loose ends to the left, rope is ready for splicing.

Splicing "Kilindo" Rope.—Proceed as with lock splice in 6-stranded rope, insert spike under two strands of two's and tuck No. 1 strand of three under spike in the *opposite* direction, keeping the strands flat and pull well home. Lift the next strand of two, the first that No. 1 went under, and tuck No. 2 as with No. 1, lift the next strand of two and tuck No. 6. Now, without drawing the spike, tuck No. 3 under spike in the *same* direction, lift the next strand of two and tuck No. 4 as with No. 3, lift the last strand of two and tuck No. 5 as before, pull all strands home and beat round. This completes the first tuck, as shown in Fig. 24.

Start this tuck with any strand, tucking each strand of three over one strand of two and under the next strand of two in rotation, working to the left, pull strands well home and beat round. This completes the second tuck. The third and fourth tucks are made exactly the same as the second tuck. Before starting the next tuck, turn one strand of each three back out of the way and proceed as before, tucking each strand of *two* over and under one strand of two. This completes the fifth tuck.

Sixth and last tuck. As before, tucking each strand of two over and under one strand of two, pull strands well home, beat round and cut off the ends. This completes the splice, as shown in Fig. 25.

Fig. 26 shows the completed splice as it appears in "Kilindo" wire rope of 18 strands. A splice of this description made of $1\frac{3}{4}$ ins. circ. 18×5 steel wire rope, recently tested at Bruntons Research Laboratory, Musselburgh, broke at tail of splice at: Breaking load, 8·5 tons; breaking load of rope 9·4 tons; spliced by T. F. P.

Single Strand Cable.—This class of cable or rope is seldom

used in mining circles, but one may come in contact with it at any time on light work, such as aviation. It is also used for carrying ropes for aerial cables. It is generally constructed with the outside wires left-hand lay, and varies from 7 to 37 wires, twisted 18 around 12 around 6 around 1, as shown in Fig. 27.

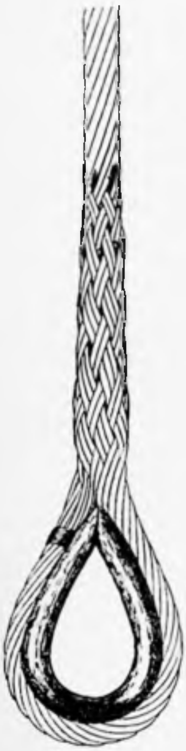


Fig. 25.

Fig. 26.

Fig. 28 shows a single strand cable of 19 wires, twisted 12 around 6 around 1, with thimble turned in and the end opened out ready for splicing; the centre wire or core may be twisted off as it is generally a different class of wire, "very soft," thus leaving 18 wires to be split up and tucked into the 12 outside wires. With the 18 loose wires make up 6 strands or 3 wires each, the 12 outside wires of main wire make up 6 strands of 2

wires each, care being taken not to get the wires twisted. Next pick up three strands or 6 wires, and tuck the first strand of three, No. 1, under the spike from left to right, as shown in Fig. 29.

Next tuck the second strand of three under the first two strands or 4 wires that No. 1 went under, and the third strand of three under the first strand or two wires that No. 2 went under. Repeat operation with other three strands of three being tucked under one strand or two wires in rotation, working to the left, pull all wires home and beat round. This completes the first tuck, as shown in Fig. 30.

Fig. 27.

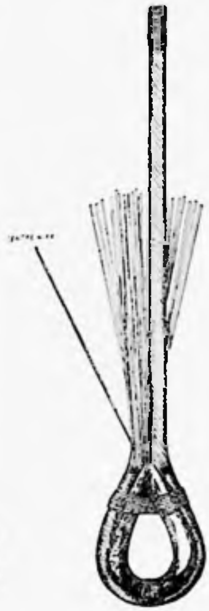


Fig. 28.

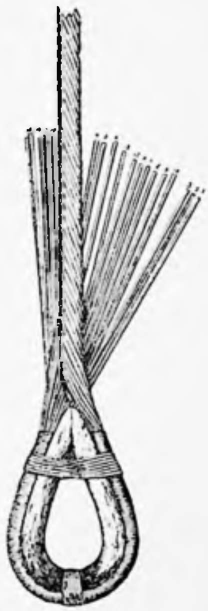


Fig. 29.

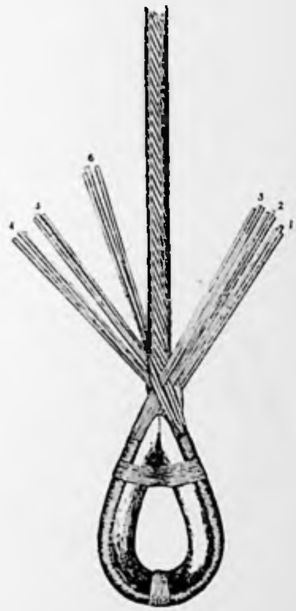


Fig. 30.

The first tuck completed, proceed as before tucking each strand of 3 in rotation over one strand of 2 and under the next strand of 2, pulling all well home and beat round. This completes the second tuck. Third tuck, proceed as with the second tuck.

Next turn back one wire from each strand of 3 and tuck the

strands of 2 wires over two and under two until all have been tucked three times, beat round and break the ends off. This completes the splice, as shown in Fig. 31. An eye splice in single strand wire of 37 wires is shown in Fig. 32.

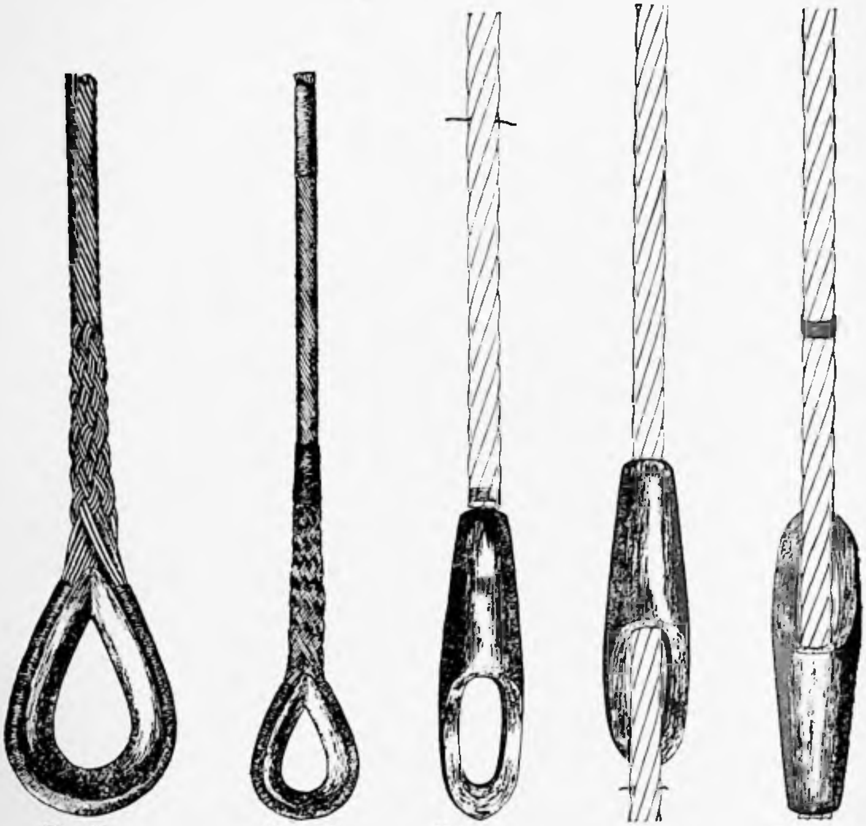


Fig. 31. Fig. 32. Fig. 33. Fig. 34. Fig. 35.

The Back Splice.—A special chapter is devoted to the socketing of wire ropes by means of white metal, but it might be advisable at this point to deal with the socketing of wire ropes by splicing.

Preparation: first put a fine wire whipping on the end that is to pass through socket, allowing sufficient rope for splicing, and mark with piece of twine under two strands. This will not obstruct the passage of socket as a whipping may

do, if it does not hand up it may shift along the rope and alter the length when fitted. (*See* Fig. 33.)

Next pass the socket over end of rope basket first, as shown in Fig. 34. Put a good soft wire binding or collar at mark, which should be, say, for a $2\frac{1}{2}$ ins. circumference rope 1 inch long, $\frac{1}{4}$ in. thick at top, and taper to the bottom. This forms a good seat for strands to bend over as shown in Fig. 35. Open out the strands for splicing, as shown in Fig. 36.

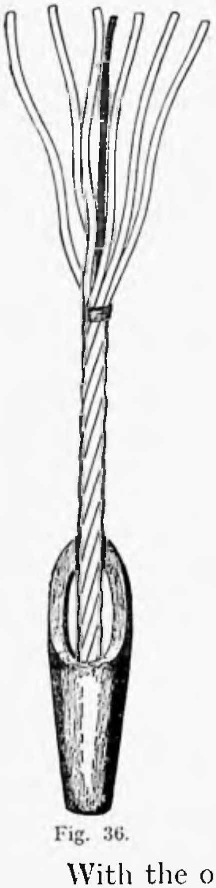


Fig. 36.

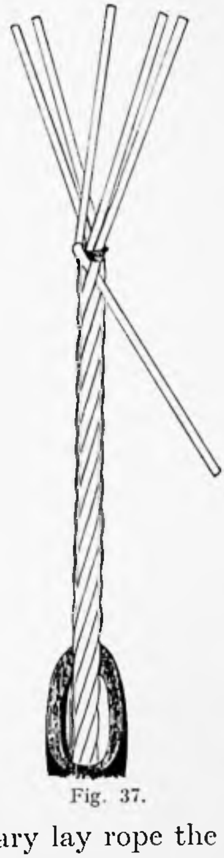


Fig. 37.


Fig. 38.


Fig. 39.

With the ordinary lay rope the turns will come out of the strands as they are tucked; with Lang's lay, it is good practice to untwist the strands before they are tucked. Start the splice by bending the first strand down over the binding, and tuck it

over one strand and under the next, working to the left, *i.e.*, against the lay, as shown in Fig. 37. Repeat same with other five strands in rotation, pull strands well home and beat round. Next cut off all ends, the splice being then complete. A round iron wedge, about the size of core, should be driven down into centre of splice, as shown in Fig. 38. If length of basket permits, two tucks may be put in, using half the strands only for the second tuck, as shown in Fig. 39.

The splice completed, pull rope well home with a secrw or tackle. When basket of socket has to be up, it is advisable to run same up with white metal; when down, this is not necessary. Fig. 39 shows a back splice of two tucks in Lang's lay rope.

Long Splice.—This splice is used for haulage and where endless ropes are required. Mark off both ends the length required for splicing which depends on the size of rope, say 48 feet, that is, 24 feet each end. Having marked each end, unlay three alternate strands from each end to within 6 inches of mark, as shown in Fig. 40, *left*. Then cut off the three remaining strands with the core and bend back at mark, as shown in Fig. 40, *right*. Lock both ends together, close up, so that the long strands pass alternately right and left, as shown in Fig. 41.

Now grip the rope on one side of the lock with tongs, unlay one short strand and lay up in its place the corresponding long strand until within 4 feet of the end. To facilitate operations, the short strand may now be cut 4 feet from the cross, the two ends measuring 8 feet. Lay up the other two long strands, the crosses being 8 feet apart; next repeat the operations with other side, cutting the ends at 4 feet and the crosses being 8 feet apart, as shown in Fig. 42.

The next operation is to run the ends in and substitute the core. It is advisable to serve the ends, this gives the outer strands a firm grip on them and prevents loose wires protruding through interstices of the strands. Grip the rope with tongs where indicated by arrow, drive the spike through centre of

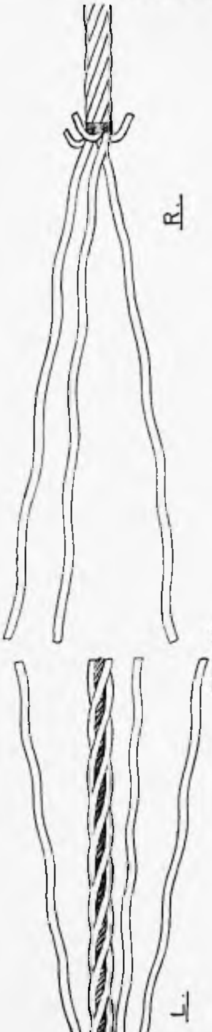


Fig. 40.

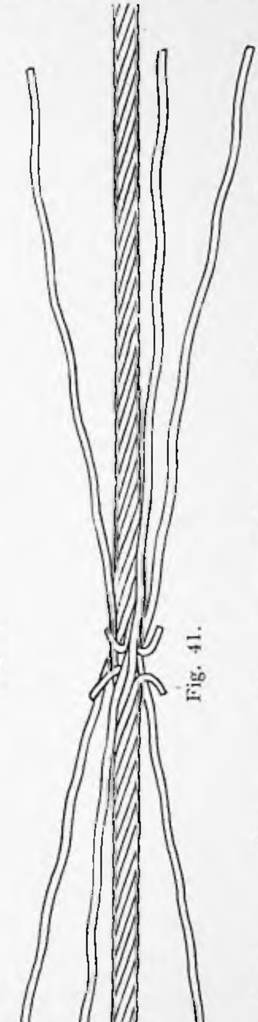


Fig. 41.

Fig. 42.

Fig. 43.

T

rope three strands in advance of the strand to be run in, and with the aid of short spike pick the core out, as shown in Fig. 43.

Run spike back towards the tongs, insert needle over the end in place of the spike, hook spoon under the end and in same place as the needle, as shown in Fig. 44.

Take two or three turns out of the strand and twist it round the rope as indicated by arrow, at the same time bring the handle of the needle and spoon together as indicated. This forces the strand into centre of rope, and by twisting the needle round the lay the strand will enter the rope one side and force the core out on the other. Cut the core close up to the end of strand. Now turn and run the opposite end in exactly the same. Now proceed and run in the other five pairs of ends in exactly the same way as the first pair.

NOTE.—Care should be taken not to run the core too far back, otherwise flat places will occur. This completes the splice, and, if correctly executed, there should be very little difference between the splice and any other portion of the rope. With a Lang's lay rope the ends of the strands are run into the right of each other, as shown in Fig. 45.

With the ordinary lay rope the ends of strands are run into the left of each other, as shown in Fig. 46.

Protection of Splices.—In many cases it is most desirable to give a splice greater protection than is afforded by marline or wire serving. This can be obtained by the adoption of flexible shields, as illustrated on page 232. These shields have the further advantage in that the splice is completely protected from all shocks and abrasion.

They are toughened after manufacture and can be used over and over again. They are specially suitable for ropes which wind on small barrels.

Method of Fixing.—Slide the shield (small end first) on the end of the rope to be spliced. Splice in the ordinary manner, and after pounding the splice into good shape (with a wooden mallet), slip the shield down to completely cover the splice.

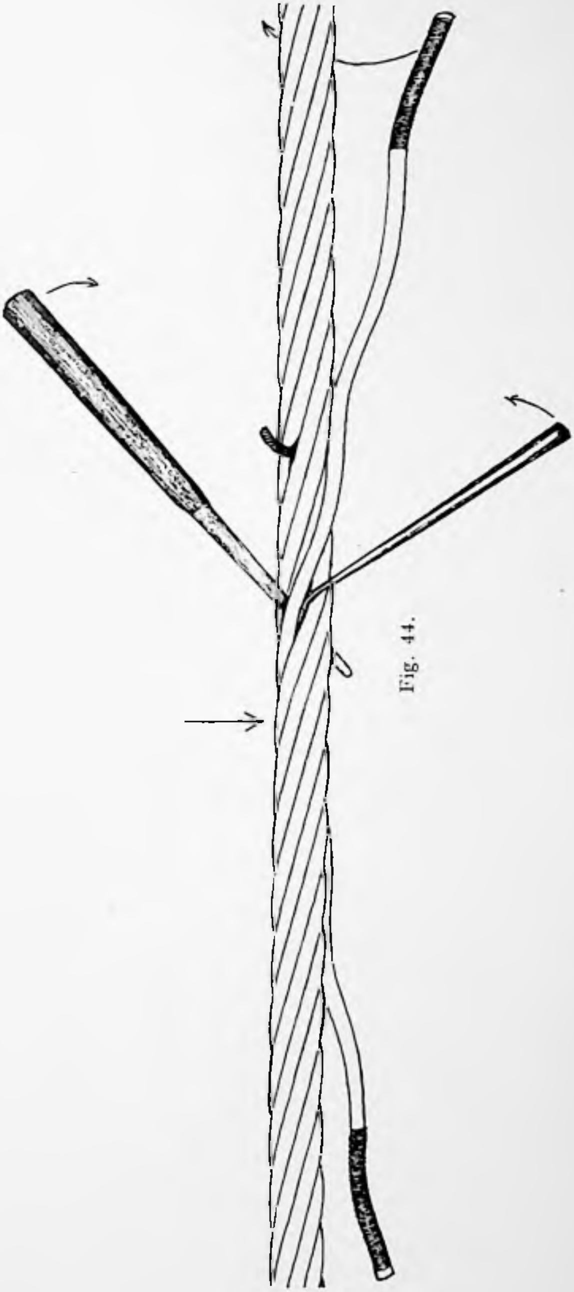
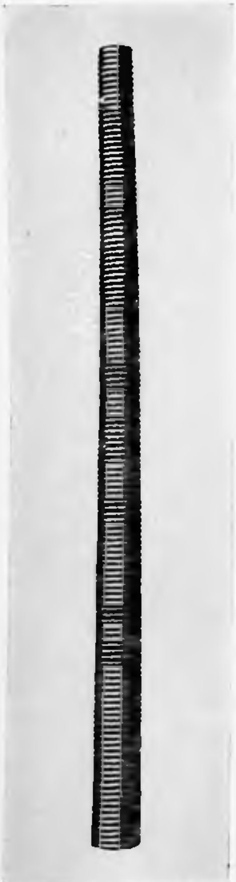


Fig. 44.

Fig. 46.

Fig. 45.



COPY

REPORT No. 93929.

The Sheffield Testing Works Ld.

PHYSICAL & CHEMICAL LABORATORIES.

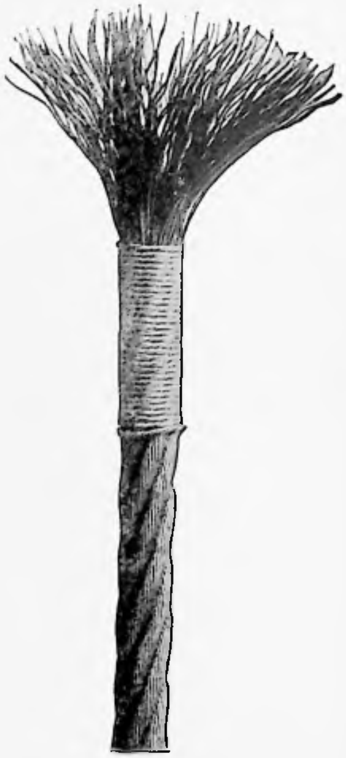
BLONK STREET, SHEFFIELD.

17th April 1919.

TEST No.	MARKS ON SPECIMEN	DESCRIBED AS	CIRC.CE OF ROPE	WEIGHT PER FATHOM	STRANDS			TOTAL NO OF WIRES	HEMP CORE	MAXIMUM STRESS		REMARKS
			INCHES	POUNDS	No OF STRANDS	No-OF WIRES	DIAM.R OF WIRE INCHES			POUNDS	TONS	
D.730	–	SHORT LENGTH OF SMALL SIZED FLEXIBLE WIRE ROPE, HAVING AN EYE AT ONE END.	1·00	PER 100 FEET 15·80	7	18 12 6 1	·015 " " " " ·018	259	WIRE	8460	LONG TONS 3·78	FIG 22 LOCK SPLICE 82·5% 4 STRANDS BROKE TOGETHER AT POSITION INDICATED IN SKETCH APPARENTLY AT THE LAST TUCK OF THE SPLICE
D.751	–	Do.	1·00	Do.	Do.	Do.	Do.	Do.	Do.	8160	LONG TONS 3·64	FIG 23 82·16% FRENCH SPLICE Do. Do.
JOHANNESBURG TEST 16th MARCH 1920												
16,377.	–	LENGTH OF IMPROVED PATENT STEEL ROPE 8 Ft. SPLICED ROUND THIMBLE ON END	2·5"	PER FOOT 1·09	6	6 1	.090"	42	BEST RUSSIAN HEMP.	48,340	SHORT TONS 24.17	LOCK SPLICE 97% Do. LAST TUCK OF SPLICE
BRUNTONS SCOTLAND												
		KILINDO S.W. ROPE THIMBLE SPLICED IN EACH END 8 F Long	1¾"		13	6 1	.056	126	HEMP	17.000	SHORT TONS 8·5	LOCK SPLICE 91·4% Do. LAST TUCK OF SPLICE

Sockets: Their Attachment to Wire Ropes.—Sockets of the proper design, if carefully and properly attached to a wire rope with white metal of a satisfactory alloy for the purpose, will give the breaking strain of the rope. When a wire rope is used with a socket attached, it is important that the socket

First Operation.—The rope must be served securely with soft wire. and the strands opened as shown for a distance equal to the length of the basket of the socket, and hemp core cut out.



Second Operation.—Separate the wires in each strand as shown. Clean them well of all grease. This can be done with petrol.

Dip the wires into a solution or equal parts of acid (hydrochloric) and water for a few minutes (not more than five), then wash thoroughly in water, and dry.

Do not use stronger acid than indicated.

be designed and attached in such a way that the full strength of the rope may be developed. Wire rope sockets should be made from carefully selected and tested steel of high strength, and be either drop forged, or well annealed cast steel, depending upon the diameter of the rope to which the socket is attached.

To develop the full strength of the rope the method of attachment is important. The method of attachment, as shown here, is the result of numerous tests in various ways of

Third Operation.—Bind the wires together as shown by means of soft wire.

Fourth Operation.—Warm the socket, then push the wires through the basket of the socket till they are even, or a little above the top. Pull the binding off to allow wires to spring out. Put clay round rope at bottom of socket to prevent metal running through.

running up sockets, and the mean result of tests shows the method described as being superior to any we have yet heard of.

When the work is done in the ordinary way the wires are bent back on each other and the basket of the socket filled in with metal, pins being used to lessen the quantity of metal

required. In following this method it is important to have all the wires engaged. Some of them creep back into the rope, thus preventing a perfect contact between the rope and the socket, consequently developing a weakness in the connection due to the disproportionate strain obtained on the strands.

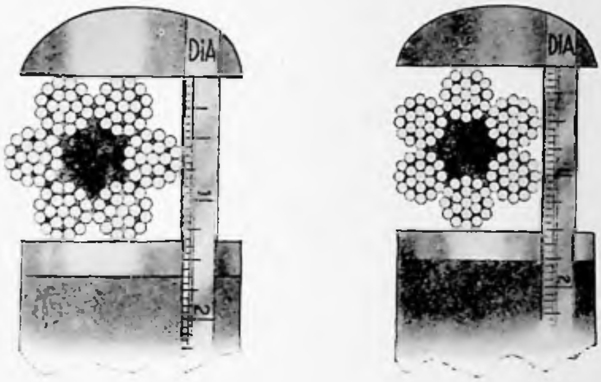
Fifth Operation.—Pour metal into basket of socket as illustrated. See that the metal is of right composition, and is not too hot to take temper out of wire.

Complete.

Tests made of sockets attached in this manner have resulted in the sockets pulling away from the rope before the load is great enough to break either rope or socket. It will be noted, in the following instructions, that we specify the proportions of acid and water to use in cleaning the wires. The strength of this solution is ample, and care should be taken not to use stronger solutions. These tend to injure the rope.

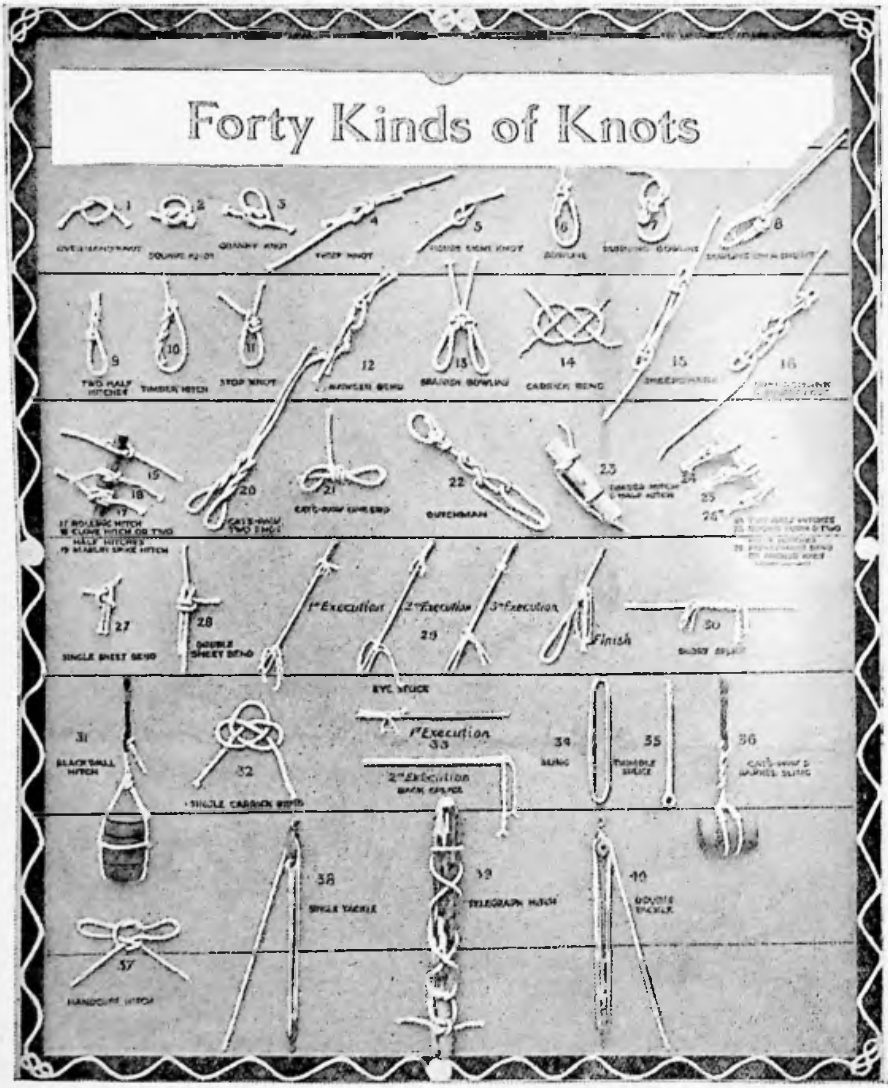
When sockets are attached in the manner recommended and described, the full strength of rope or socket is obtained.

How to Measure Wire Rope.—The diameter of a wire rope is the diameter of a circle which will just enclose all the strands. Care should be taken in gauging a wire rope to take the greatest and not the smallest diametrical dimensions.



Lubrication of Ropes.—Both winding and hauling ropes should be well lubricated as soon as they are put to work. The grease used must be neutral, neither acid nor alkaline, and should remain so under all conditions. Grease has been found to change after being exposed to the atmosphere. The lubricating process should be frequently done with a new rope until the interstices between wires and strands and strands and rope are well filled; this prevents damp striking into the rope, and is most important. By keeping ropes well lubricated the life is materially increased.

To an engineer every knot, splice or loop has its own particular purpose and use. For instance, in raising derricks, masts or poles, or in the building of pontoon bridges, it is necessary for the engineers to work not only very rapidly but often in the dark, and the success of the whole undertaking depends many times upon the kind of knot used in the various positions.


Forty Kinds of Knots
1st Execution
2nd Execution
3rd Execution
Finish
1st Execution
2nd Execution

Forty Kinds of Knots

1. Overhand Knot.—The starting of a square knot.
2. The Square Knot.—A non-slipping knot.
3. Granny Knot.—Useless knot that will slip when tied up; the majority of people use it when tying up bundles.
4. Thief Knot.—This knot will slip.
5. Figure-of-eight Knot.—Used for a stop knot.
6. Bowline.—Used as a non-slippable loop, very useful.
7. Running Bowline.—Same as bowline, only a slip noose.
8. Bowline on a Bight.—Used for boatswain's chair.
9. Two Half Hitches.—Used in tying up a boat to a landing or making it fast; easily undone.
10. Timber Hitch.—Used by timbermen for pulling logs.
11. Stop Knot.—Used on a tackle.
12. Hawser Bend.—Fasten two ends together to make fast.
13. Spanish Bowline.—Used for boatswain's chair.
14. Carrick Bend.—Used on the top of a gin pole or mast to hold it erect; in four ends and made fast on the ground.
15. Sheepshank.—To decrease the length of a line.
16. Sheepshank and Square Knot.—Used as above, only a square knot to make it a little more substantial.
17. Rolling Hitch.—Taking a round for secure hold.
18. Clove Hitch, or Two Half Hitches.—Same as above.
19. Marline-spike Hitch.—Used on a single halliard.
20. Catspaw, Two Ends.—Used on a barrel.
21. Catspaw, One End.—Used for barrel sling.
22. Dutchman.—Used to hold loads on waggon.
23. Timber Hitch and Half Hitch.—Used on timber.
24. Two Half Hitches.—Used to give hold on timber.
25. Round Turn and Two Half Hitches.—Same as above.
26. Fisherman's Bend, or Anchor Knot.—Used on an anchor.
27. Single Sheet Bend.—Used for tying two ends together and very easy to open.
28. Double Sheet Bend.—Same as above.
29. Eye Splice.—To put two eyes on ends of ropes.
30. Short Splice.—To put two ropes together substantially but increasing the thickness.
31. Blackwall Hitch and Barrel Sling.—A simple knot that is used on any weight, and as soon as the weight is taken off the knot opens.
32. Single Carrick Bend.—Used on top of a gin pole or mast; only with two ends.
33. Back Splice.—Used to keep ends from unravelling.
34. Sling.—For lowering barrels or boxes.
35. Thimble Splice.—To keep the eye on end of rope from tearing out.
36. Catspaw and Barrel Sling.—Same as 34.
37. Handcuff Hitch.—To convey prisoners.
38. Single Tackle.—For lowering anything or for hoisting purposes; the pull is equal to half of the load.
39. Telegraph Hitch.—Used around a pole that will hold a strain; at the same time is easily undone after the load is taken off.
40. Double Tackle—A tackle on which the pull is equal to one-quarter of a load.

APPENDIX

APPENDIX.

With reference to this Appendix see page 184, Chapter V.

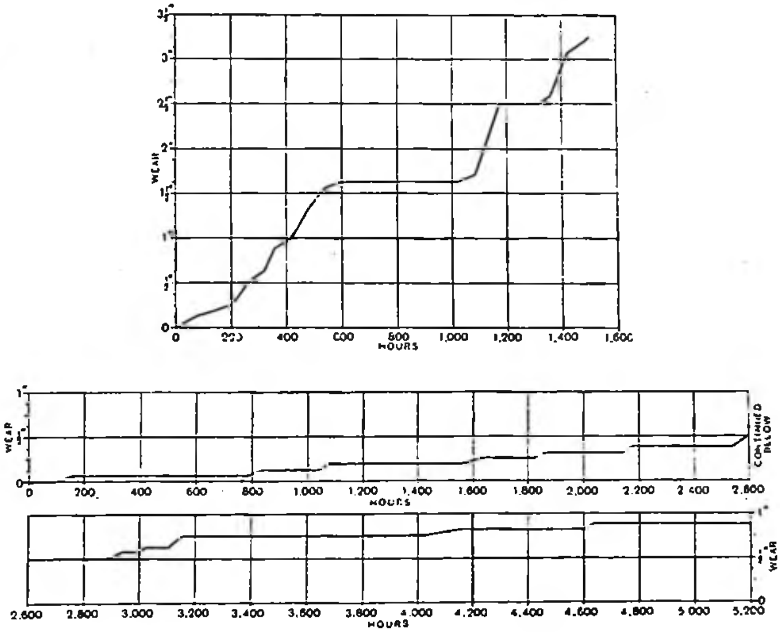


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TABLE.

AVERAGE LIFE IN HOURS OF COMPONENTS OF DREDGER BUCKET CHAINS.

	Material.	Dredger No. 3.	Dredgers Nos. 4 and 5.	Dredgers Nos. 6 and 7.
Size of bucket, cub. ft.	—	21	10	27
Top tumblers - -	High-carbon steel	2,207	2,530	2,366
Bottom tumblers - -	,, ,,	2,207	2,530	2,828
Bucket backs - -	Medium carbon steel	12,000	10,000	5,660
Pins - - - - -	Manganese-steel	2,200	2,970	2,930
Bucket bushes - -	,, ,,	2,140	2,000	3,880
Link bushes - - -	,, ,,	2,080	2,000	2,960
Ladder rollers - -	"Tyne" metal	5,650	4,800	4,680
Links - - - -	32-ton steel	8,800	11,650	9,800
Duration of record -	—	11,036	22,773	22,625

(By kind permission of R. J. N. Willcox, M.Inst.Mech.Eng.)

TABLE.

BEARING PRESSURES IN BUCKET CHAINS.

Dredger.	Bucket capacity, cub. ft.	Angle of ladder.	Bearing.	Pressure, lb. per sq. in.		
				Static.	Fast gear.	Slow gear.
Nos. 4 & 5	10	22°	(a) Bottom tumbler	557	697	746
			(b) Top tumbler -	640	840	920
			(c) Link pins - -	2,780	4,180	4,630
,,	10	45	(a) ,, ,, -	239	379	418
			(b) ,, ,, -	568	832	930
			(c) ,, ,, -	2,360	3,750	4,200
"India"	15	23	(a) ,, ,, -	310	385	418
			(b) ,, ,, -	825	945	1,020
			(c) ,, ,, -	3,150	3,150	3,150
,,	15	45	(a) ,, ,, -	163	232	268
			(b) ,, ,, -	820	960	1,060
			(c) ,, ,, -	2,380	2,380	2,670
No. 3	20	25	(a) ,, ,, -	252	305	323
			(b) ,, ,, -	467	585	627
			(c) ,, ,, -	2,480	3,400	3,700
,,	20	42	(a) ,, ,, -	159	212	230
			(b) ,, ,, -	462	590	640
			(c) ,, ,, -	2,290	3,090	3,150
Nos. 6 & 7	27	25	(a) ,, ,, -	342	424	470
			(b) ,, ,, -	364	427	480
			(c) ,, ,, -	3,440	3,440	3,440
,,	27	45	(a) ,, ,, -	108	187	230
			(b) ,, ,, -	350	430	474
			(c) , ,, -	2,420	2,820	3,500
No. 10	14	23	(a) ,, ,, -	304	420	—
			(b) ,, ,, -	372	488	—
			(c) ,, ,, -	2,820	2,820	—
,,	14	50	(a) ,, ,, -	113	220	—
			(b) ,, ,, -	410	527	—
			(c) ,, ,, -	2,260	2,920	—

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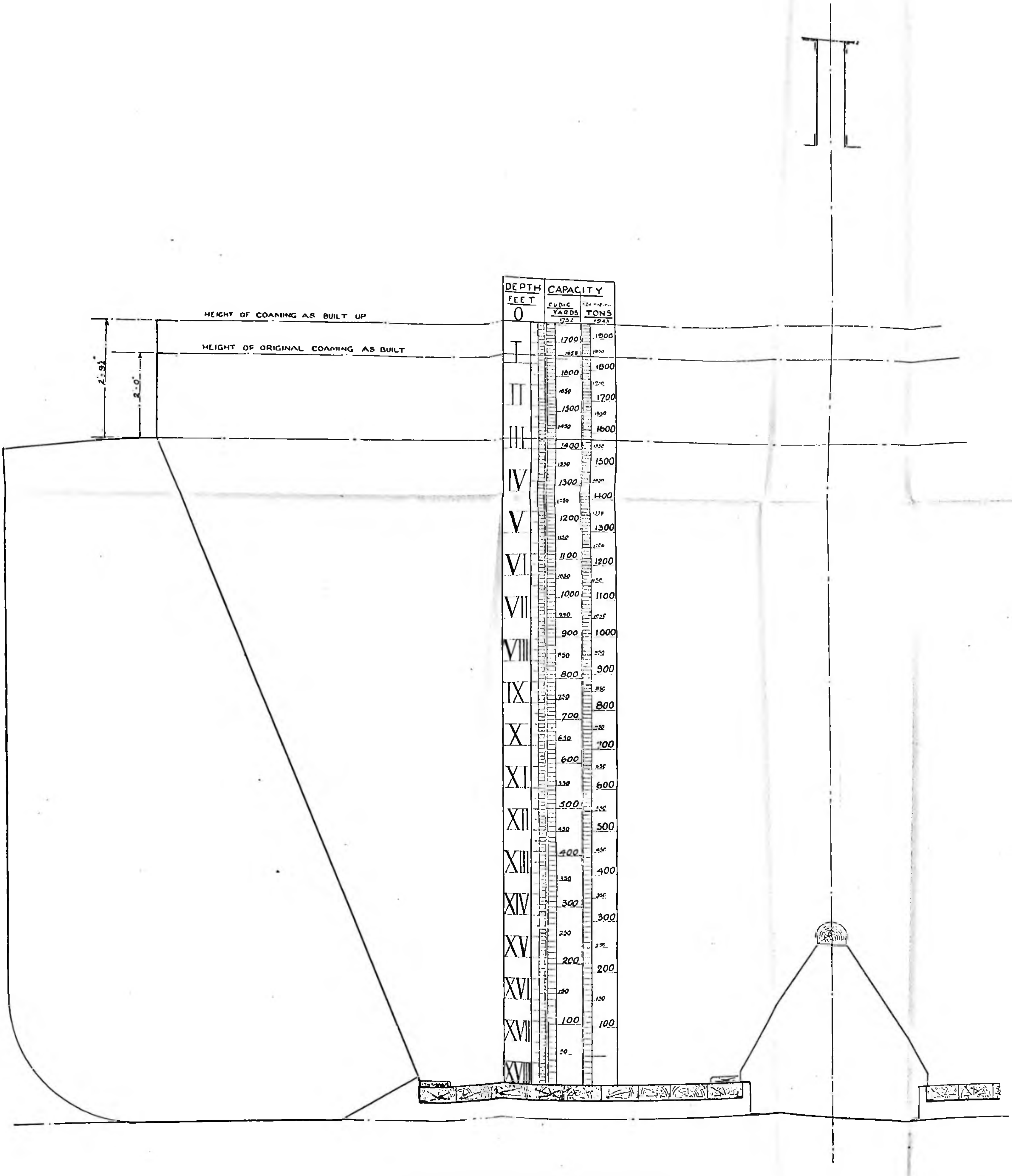

LOADING OR DISPLACEMENT SCALE FOR HOPPERS

To face page 244.

INDEX

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INDEX

DREDGER SPARES

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